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EFFECTS OF VISUAL-PROPRIOCEPTIVE CUE CONFLICTS ON HUMAN TRACKING PERFORMANCE

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The purpose of this experiment was to investigate operator performance in an environment which was highly conducive to visual-proprioceptive conflict. The experimental task required that subjects maneuver a simulated remotely piloted vehicle from a simulated airborne control station (i.e., "mother ship"). The vehicle and/or the station were given gust-like disturbances on pitch and/or roll. In a between groups design the performance of pilots, navigators, and non-rated Air Force officers was compared under conditions of conflict (e.g., visual roll right and roll left motion), non-conflict, motion only, and no motion. To maintain adequate performance it was necessary for the subjects to disregard sensations of motion. The results revealed that the conditions of conflict engendered the highest proportion of reversal errors by all subjects. The past experience of pilots did not help them overcome the

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effects of conflict as measured by reversal errors, but it did help them reduce response latencies. The effects of practice were evidenced primarily by a reduction of reversal errors under conditions of conflict. Strong evidence was found to support the notion that motion plays an alerting function and also provides information on the direction of attitude changes.

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INTRODUCTION

Man is well adapted to moving about in the terrestrial world in which he lives. The visible world provides relatively constant and stable environmental features which allow him to maintain his orientation. The unchanging downward force of gravity provides him with a stable reference for judging the orientation of his body with respect to ground. Specialized sensor organs, evolved over millions of years, provide him with the internal (i.e., physiological and anatomical) and the external (i.e., environmental) information he needs for spatially oriented behavior. When man encounters unfamiliar combinations of sensory information, as when piloting an aircraft, he must make a new adaptation to a more complex environment.

In piloting tasks the visual information received from flight instruments and from the outside world, and the sensations of motion arising from proprioceptive[1] sensory mechanisms provide the pilot with the information he needs to perform his manual control activities. It is often the case, however, that visual-proprioceptive data are in conflict and result in what Clark and Graybiel (cited in Benson, 1965) termed spatial disorientation. In this situation, the pilot may fail to

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[1]The term proprioception, as distinguished from kinesthesis, is used to refer to the sensations arising from receptors of the nonauditory labyrinth of the inner ear and from muscles, tendons, and joints (Adams, 1968). Kinesthesis refers to sensations of movement arising from receptors other than the nonauditory labyrinth.

interpret correctly the attitude (i.e., positional relationship to gravity) of himself and his aircraft with respect to the ground. Conflicts may engender confusions or illusions that appear to the pilot to be as compelling as veridical perception. In either case, spatial disorientation often leads to inappropriate manual control activities. When a pilot of a high performance aircraft accelerates during a night takeoff, for example, he may have the false sensation of being tilted backward. If he attempts to correct for this sensation by moving the control stick forward (nose down), the consequences of this activity may be a serious threat to safety and is occasionally tragic.

The sensory data most often interpreted to be in conflict with visual ones arise from the receptors of the nonauditory labyrinth of the inner ear (i.e., the vestibular apparatus consisting of the semicircular canals and the otolith organs). Any change in the rate of angular or linear motion (i.e., acceleration or deceleration) is the adequate stimulus for the vestibular apparatus and the source of potential conflict. When flying into a cloud, for example, a reduction in speed may be interpreted by the pilot as a dive even though his instruments inform him that he is flying level to the ground. Similarly, subthreshold angular accelerations will not be detected by the pilot and may lead him to think that he is flying straight and level even though his instruments indicate that he is banking.

To avoid the consequences of conflict, training programs have stressed that the pilot must rely on visual cues provided by instrument displays and ignore the proprioceptive cues of motion. Although these

training procedures have been useful, they have not eliminated spatial disorientation.

Purpose and Scope

The purpose of the research to be reported herein was to investigate operator performance in an environment which is highly conducive to visual-proprioceptive conflicts. The experimental task required that subjects maneuver a simulated remotely piloted vehicle from an airborne control station (i.e., a "mother ship"). Since the visual inputs received from the vehicle are independent of the motion inputs from the control station in this environment, it was necessary for the operators to ignore sensations of motion in order to maintain adequate performance. Research has shown, however, that motion cues are extremely compelling and are not easily disregarded even by seasoned operators.

A background for the various psychological factors pertinent to spatial orientation is presented prior to a detailed statement of the problems investigated in this research. The visual factors of spatial orientation are presented first and this is followed with a comparison of visual and postural (i.e., gravitational) factors. The effect of motion compatibility (i.e., control-display relationships) as it relates to problems of orientation (and disorientation) is discussed next. This topic has been the subject of a considerable amount of research dealing with the various types of aircraft attitude displays and their potential effect on spatial orientation. Discussed last are the effects of

motion on operator training and performance, a subject of current interest and controversy.

Background

Visual Factors

It has been known for many years that human performance improves when stimuli are oriented vertically or horizontally rather than obliquely. Emsley (1925) first noted that acuity was lowest for lines at 45° and attributed the effect to astigmatism. When corrective lenses were used, however, the preference for vertical and horizontal lines over oblique ones continued. Emsley referred to this phenomenon as "residual astigmatism" and explained that it was due to the optical lens, the retina or optic nerve. Howard and Templeton (1966) reviewed the literature and proposed several classes of theoretical explanations for the effect. In general, these authors concluded that the studies were unable to eliminate astigmatism as a possible cause.

More recently, Appelle (1972) prepared a comprehensive review of the literature on the phenomenon, which he proceeded to coin the "oblique effect" (this term will be used throughout this discussion). According to Appelle, the earliest account of the oblique effect was reported by Jastrow (1893) who found that man could make very precise judgments of visual horizontals and verticals. He thought that this was due to man's common experience with these two visual orientations. The preference for horizontals and verticals over the oblique appears in many organisms other than man. Thus, for example, Sutherland

(1957, 1958) found that octopuses could easily discriminate between horizontal and vertical rectangles, but not between two oblique ones.

Extensive research has been conducted in an effort to locate the origin of the oblique effect by means of behavioral, anatomical and neurophysiological studies. Attneave and Olson (1967) conducted discrimination reaction time studies to determine whether the effect was due to the physical orientation of the stimulus or to the retinal orientation. They found that the subjects identified horizontal and vertical stimuli faster than oblique ones with the head upright. When the subjects observed the stimuli with the head tilted, they responded faster to the physical verticals and horizontals (i.e., the retinal obliques) than to the physical oblique (i.e., the retinal horizontal and vertical). These investigators concluded that the origin of the oblique effect must be attributed to physical (i.e., environmental) rather than to retinal orientation and indicated that "the perceptual system makes allowance or correction for head position, on the basis of proprioceptive information, before the effect occurs" (p. 155). Attneave and Reid (1968), on the other hand, concluded that the critical factor was the invariance of the perceived orientation of the stimulus rather than the physical or retinal orientation. In their experiment they were able to change the subject's frame of reference by means of instructions (e.g., "always think of the top of your head as up"). Thus, according to these investigators, the orientation of the reference system in man is under voluntary and proprioceptive control.

Substantial neurophysiological evidence is accumulating to show that the locus of the oblique effect is central rather than retinal. Microelectronic studies of neural functioning (e.g., Hubel & Wiesel, 1962) have shown that cortical cells of cats respond maximally to bars and contours of particular position and orientation. More appropriate to the present issue, Pettigrew, Nikara, and Bishop (1968) found a greater proportion of cells in the cat that were selectively sensitive to visual verticals and horizontals. Maffei and Campbell (1970) simultaneously recorded evoked potentials and electroretinograms from the occipital scalp of humans. Maximum amplitude of the potentials were evoked by vertical and horizontal gratings in contrast to oblique ones. No such inequality was found in the electroretinogram recordings. The investigators concluded that the resolving power in oblique orientations was less than in the vertical and horizontal and that the locus of the effect was somewhere between the site of origin of the electroretinogram and the evoked potential of the cortex. Finally, Mansfield (1974) examined the receptive field properties of neurons in the striate cortex of rhesus monkeys. Neurons sampled from the foveal projection region responded maximally to vertical and horizontal stimuli, but relatively few responded to stimuli at oblique orientations. This effect, however, was diminished with distances from the region of the striate cortex corresponding to an area 6° to 8° away from the fovea. In a psychophysical experiment with humans, Mansfield reported that the acuity for vertical and horizontal stimuli relative to that of obliques decreased with retinal eccentricity. Thus, Mansfield suggested "the hypothesis

that the orientation effect in man is the result of a predominance of cortical neurons with receptive fields optimally sensitive to horizontal and vertical stimuli" (p. 1134).

Whether the oblique effect can be attributed to prenatal development or to early experience with the environment has been the subject of considerable interest and controversy. One interpretation holds that orientation specificity is a product of experience; the responsiveness of neural units to vertical and horizontal contours is said to be due to the predominance of lines in these two orientations in the carpentered environment in which man lives. Evidence for this supposition has been reported recently by several investigators. Annis and Frost (1973), for example, noted that the Cree Indians of Canada are reared in an environment containing a heterogeneous array of contours, including obliques. When the visual acuity of these Indians was compared to that of a group of Euro-Canadians, it was found that the Indians failed to reveal the oblique effect; whereas the Euro-Canadians did. Timney and Muir (1976), on the other hand, found no difference between Caucasians reared in a carpentered environment and Chinese subjects who had lived in Hong Kong during their youth.

Evidence to show that early visual experience can have neurophysiological consequences has been sought by many investigators. Hubel and Wiesel (1963) found that the characteristics of cells in the visual cortex of kittens a few days old to patterned stimuli were similar to those of adult cats. Since the kittens had not been exposed to patterned stimuli the results tended to suggest that visual

capabilities develop early in life. When an animal's early visual experience is restricted, however, the preferred orientation of neurons to various stimulus orientations is altered. Hirsch and Spinelli (1970) found that cats raised from birth with one eye viewing horizontal lines and other vertical lines, had neurons with receptive fields that responded to only these two orientations. No oblique fields were found, and units with horizontal or vertical fields responded only when the appropriate eye was exposed to horizontal or vertical lines. In contrast, Stryker and Sherk (1975) used a different experimental procedure and found that kittens exposed to oriented stripes early in life and then placed in darkness did not show orientation specificity. Finally, Leventhal and Hirsch (1975) found that exposing young cats to horizontal and vertical lines only, resulted in profound modifications in the distribution of neural units with orientation preferences as found by Hirsch and Spinelli. The cortical cells of cats exposed to diagonals only did not show a corresponding modification of orientation preferences. Most of these cells responded to horizontal and vertical lines and the remaining cells responded preferentially to diagonals and were activated only by the eye which had been exposed to the diagonals. These cells were not influenced by early experience with the environment, while those that responsed preferentially to diagonal lines were. The investigators suggested that cells with diagonal preferences may have been recruited from neurons initially uncommitted and that orientation specificity depended on early experience with the environment.

As noted from the studies cited above, there is no compelling evidence to support either hypothesis. Recent reviews on the topic (Grobstein & Chow, 1975; Kolata, 1975) have reached the same conclusion, namely, that critical information is still lacking and the question of which hypothesis is correct is still the subject of debate. Grobstein and Chow suggested that there may be "some genetically determined range of possible orientation specificities for an individual neuron within which the actual orientation specificity is realized by experience" (p. 356). Furthermore, these investigators stated: "Perhaps it is some more subtle role, such as aligning some fundamental retinal axes, against which orientation selectivities are defined, with body axes or some other axes relevant to motor control" (p. 357). While the possible association of early physiological development of orientation specificity with body axes is not known, there are many behavioral studies that have attempted to determine the relative contribution of visual and postural factors on man's ability to orient himself in the environment.

Visual Versus Postural Factors

It is well known that gravity is a significant feature of the environment to which an organism orients itself. Vestibular and kinesthetic stimuli arising from the forces of gravity provide man with extremely compelling postural cues. When blindfolded subjects are seated in a tilting chair, for example, they are capable of restoring their position to the true vertical with considerable accuracy even in the absence of either vestibular or cutaneous cues. As revealed in the

preceding paragraphs, however, gravity is not the only determinant of orientation.

The relative contribution of visual and gravitational factors has been the subject of controversy for many years. The dispute can be traced to views presented by Koffka (1935). According to Koffka, the directions of the apparent horizontal and vertical are determined by the visual field of view. In support of his theory, he noted that the vertical and horizontal are affected by the visual surroundings. He described an experience he had while traveling up a mountain in a train. When he used the window as a frame of reference, the trees appeared to be growing at an angle to gravity, but with his head out of the window the trees looked vertical. When he withdrew his head from the window the trees continued to appear vertical, but the window frame appeared tilted. According to Koffka, the visual field creates its own framework; objects are seen to be upright by virtue of this framework. Koffka's formulation of this view was based on an experiment reported earlier by Wertheimer (1912). In that experiment, Wertheimer observed that when a subject looked into a tilted mirror which displaced the image of the room in which he was standing, the room came gradually to look upright.

Gibson and Mowrer (1938) proposed a fundamentally different emphasis from that suggested by Koffka on the relative contribution of visual and postural factors to orientation. These investigators acknowledged the importance of vision but concluded that orientation in space is anchored primarily to postural factors. In cases of

conflict, postural factors dominate and were thought to be genetically primary. Disorientation reported by aircraft pilots, according to Gibson and Mowrer, simply demonstrated that vision contributed to orientation, but did not necessarily dominate.

Asch and Witkin (1948a) repeated the tilting mirror experiment reported by Wertheimer, but had subjects judge when a pivoted rod was set parallel to the body of the subject. The experiment was conducted with and without a reduction tube. Without the tube, deviations from the true vertical were smaller than with the tube. In other experiments Asch and Witkin (1948b) used a tilting room rather than a mirror. The subjects sat in a chair that could be tilted independently of the room. Subjects judged when a rod was vertical or horizontal to the room walls under various conditions (e.g., with and without a reduction tube, with both the room and chair tilted in the same or opposite directions). Finally, Witkin and Asch (1948) used a rod placed within a square frame and nothing else in view. Two frame positions (left and right in the subject's frontal plane) and two body positions (upright and 28° left) were used. The results of all these experiments revealed that the visual framework affected the subject's judgments more than tilting the chair. Witkin concluded that visual factors were more important than postural ones in judgments of verticality.

In contrast to Witkin, Boring (cited in Howard & Templeton 1966) reported an experiment in which subjects set a rod to the vertical. Using a frame that when tilted went beyond the rod, Boring found that there was no difference in either the constant error or the average

error between two conditions: when the frame and body were tilted to the same side and when tilted to opposite sides. Boring concluded that the visual frame had no effect on judgments of verticality. Mann (1952) suggested that it was necessary to supplement Boring's experiment by increasing the strength (i.e., size) of the visual stimulus to the point where the subject identified himself with the visual framework. Like Witkin he used the tilting chair and room test (rather than the smaller rod and frame used by Boring) and like Boring he had the subjects themselves adjust the rod to the gravitational vertical. The room and chair were set up to 30° left and/or right. In support of Gibson and Mowrer, Mann found that tilting the chair alone had little effect on the apparent vertical. In agreement with Witkin, however, he found the greatest error in the condition in which the room and chair were tilted in the opposite direction. When the visual stimulus in this situation is increased in size to the point where the subject identifies himself with the visual framework, the resultant is a conflict between visual and gravitational stimuli. Mann concluded that Gibson's hypothesis needed a qualifying statement to the effect that proprioceptive stimulus variables dominate until the visual variables are sufficiently effective to produce conflict. Under conditions of conflict a compromise judgment is made.

The contradictory results summarized in the preceding paragraphs led Gibson (1952,1966) to modify his view. He maintained that the perceived vertical is determined by both visual and postural factors. He stated:

> To each degree of variation in retinal stimulation there is a corresponding degree of variation in kinesthetic stimulation;

> the two are coupled together . . . In the case of reciprocal visual-proprioceptive stimulation, the coupled variables combine to form an invariant resultant which is in correspondence with the objective direction of gravity and which provides the stimulus for a univocal impression of the vertical . . . In the case of a discrepant visual-proprioceptive stimulation, the coupled variables do not yield an invariant. (Gibson, 1952, p. 373)

When visual and postural determinants of verticality do not agree (i.e., are in conflict), perception of body posture becomes equivocal and disorientation may occur. To resolve these conflicts, according to Gibson (1966), man "must accept the visual information and reject the postural, or accept the postural information and reject the visual, or alternate between the two, or compromise between the two" (p. 297). Thus, when subjected to an environment that tends to produce conflicts, man must find and learn to use cues which provide him with an adequate frame of reference of position orientation and disregard those that do not.

In a general review of his studies on the perception of the upright, Witkin (1959) concluded that the question of which of the two standards (visual vs. postural) utilized is more important was unanswerable. Encountered in most of the experiments were marked individual differences. Witkin stated that subjects "who in the rod-and-frame test were able to adjust the rod close to the true upright by reference to body position were also able to make their bodies straight in the tilting-room-tilting-chair test. Others, consistently guided by the visual framework, tended to align the rod with the tilted frame and their own bodies with the tilted room" (p. 52). Also, it had been determined earlier (Mann &

Boring, 1953) that the instructions to subjects can have a profound effect on the perception of verticality in these experiments. They compared naive subjects with sophisticated subjects who had been told to set the rod to the gravitational vertical. The naive subjects produced larger constant and average errors. Finally, Weiner (1955) manipulated training variables and found that subjects "learned to perceptually reorganize the potency given postural and visual cues" (p. 372).

Motion Compatibility

The visual and postural factors discussed in the preceding paragraphs were concerned with problems of orientation when the subject was in a stationary position. The problem of orientation becomes immensely more difficult when the subject is asked to perform in an environment that provides movement in space.

Man is well adapted to use visual and gravitational information within the general framework of terrestrial living. In a flight situation, however, the pilot of an aircraft is subjected to linear and angular accelerations that may be insufficient to stimulate vestibular receptors. This situation may result in the pilot's failure to appreciate correctly the position, or changes in position of himself as well as his aircraft, with respect to earth. As noted earlier, visual cues become important as they provide a means to maintain orientation.

There are two major sources from which a pilot obtains visual information relevant to orientation: attitude instruments and the external scene as viewed through the windshield. It is well known that

orientation in flight is more easily achieved under visual ground contact conditions than under instrument flight. The former provides changing patterns of scenes that can be integrated with the vestibular and kinesthetic receptors. The instruments, however, bear little resemblance to the external scene and the perceptual cues for orientation must be learned through adequate training procedures. Failure to interpret the instruments correctly may lead the pilot to misinterpret his position in space and result in spatial disorientation.

The physiological origins of spatial orientation, and disorientation, have been investigated for many years. A discussion on this topic, however, is well beyond the scope of the present review. Excellent surveys have been prepared by Benson (1965), Clark (1963), Clark (1970), Graybiel (1973), Howard and Templeton (1966), and Peters (1969). The discussion which follows will be limited to behavioral investigations on the ways in which motion compatibility affects a pilot's capability to orient himself in flight.

Motion compatibility refers to the direction of motion that a display element appears to move in association with the movement of a control. The relationship between a control movement and its effect, which is expected by most individuals, was referred to as the "population stereotype" by Fitts (1951). A control-display relationship which conforms to this stereotype is said to be "compatible" (Fitts & Seeger, 1953). A comprehensive review of the research conducted on the directional relationships of various controls and displays other than aircraft attitude indicators was prepared by

Loveless (1962). The primary interest in the present discussion is that of motion compatibility problems associated with aircraft attitude displays and their relationships to spatial orientation.

The most commonly used instrument to provide aircraft attitude information is the artificial horizon display (or moving horizon display). Since this display presents a serious relative motion problem, it may be also stated that it has received the greatest amount of systematic study. This instrument contains a gyro-stabilized bar that remains fixed relative to the position of the earth's horizon. While the horizon bar should result in a stationary reference framework, it actually is perceived as moving with respect to the outer frame of the display (i.e., the instrument panel). What is perceived as a moving element in this display may appear to move in the wrong way to the untrained observer and create serious problems of motion compatibility. Even the highly trained pilot may perceive the stationary frame of reference as moving during moments of stress. In this type of situation, the pilot may revert to a more natural mode of responding (the population stereotype) and move the control in the wrong direction, thus executing a reversal error.

Perhaps the earliest systematic investigation of pilot errors was reported by Fitts and Jones (1947). To determine the best method for designing aircraft instruments to improve pilot performance and reduce accidents, these investigators collected and analyzed accounts of 270 errors made by pilots. Of these, 19 were reversal errors resulting from misinterpreting the direction of bank from artificial horizon

displays. The result of such errors, of course, is to increase the amount of bank error already present. While 19 errors appear to be relatively few the consequences resulting from one could be tragic.

The problem of motion compatibility may be restated in terms of what the pilot regards as a frame of reference. The operator may consider his vehicle the frame of reference and the external world as moving about the vehicle (an inside-out frame of reference). This frame of reference is represented by displays that show fixed external references as moving, such as the artificial horizon display. On the other hand, the operator may consider the external world as the frame of reference and the vehicle as moving against the world (outside-in frame of reference). This type of frame of reference may be represented by a display that shows a miniature moving aircraft against a horizon that is fixed with respect to the instrument panel. Whichever type of display is used, however, it is always important that the pilot's frame of reference be one in which he considers his aircraft as moving; otherwise he may become disoriented and make reversal errors.

The relative merit of artificial horizon and moving airplane displays has been the subject of many systematic investigations, most of which have favored the latter display (Kelley, 1968; Kelley, de Groot, & Bowen, 1961). Recently, Johnson and Roscoe (1972) prepared a review of the literature, appropriately titled "What moves, the airplane or the world?" and stated the following: "Despite the extensive experimental evidence favoring the moving-airplane presentation, the issue

is not settled after nearly half a century of controversy. The validity of results from ground-based simulator experiments has not been established for questions in which the physical acceleration cues are believed to be important, and the results of flight experiments are inconclusive" (p. 112).

A basic problem with conventional artificial horizon displays is that the pilot population has overlearned their use. While other types of displays, such as the outside-in moving airplane display, have resulted in superior performance by non-pilots, pilots may revert back to old habits under stressful situations. Thus, it can be safely asserted that any display utilizing motion relationships which are compatible with the operator's response tendencies result in a reduction of reversal errors at any level of experience.

Attempts have been made to develop displays that represent a compromise between the artificial horizon and the moving airplane displays. The kinelog, developed by Fogel (1959), is an example. This display is based on the known fact that pilots do not have problems with conventional horizon displays while performing routine maneuvers. Control reversals usually result from responses associated with changes in attitude due to air gusts or by changes that are unnoticed by the pilot for brief periods. Accordingly, the kinelog display was developed to present both an artificial horizon and a moving airplane. When the aircraft deviates from level flight in pitch or roll, the display first shows changes in the moving airplane symbol (outside-in) and then gradually shifts to the artificial horizon (inside-out) configuration.

A similar, but simpler display was proposed by Roscoe (1968) and described by Jacobs, Williges, and Roscoe (1973). This display, which is based on the frequency separation principle, retained the artificial horizon, but presented the aileron position (an approximation of roll rate) on the airplane symbol. An aileron deflection provides immediate (and therefore predictive information on bank attitude changes) rotation of the symbol in a direction compatible with the control. Thus, it was claimed that this display was compatible with the expectations of non-pilots and also provided cues to which experienced pilots had become accustomed.

One question remains: Why are artificial horizon displays still used? Since pilots do not seem to have problems with routine contact flight, it has been assumed that the displays should be an analog of what they see through an aircraft windshield. Problems occur, however, when the pilot shifts his attention from the terrain as seen through the windshield to the artificial horizon display. Grether (1947) suggested that the cause of such problems is due to a shift of what is considered figure and ground. In normal flight the horizon is considered by the pilot to be a stable frame of reference (or ground) against which his aircraft moves. When the pilot shifts his attention to the artificial horizon display, however, the aircraft cockpit becomes the stable reference (or ground) and the horizon bar is perceived as moving and reacted to as figure. Accordingly, Grether concluded that the artificial horizon bar could not be substituted for the true horizon. It has been suggested that this problem could be due to the relatively

small size of the attitude display relative to the scene as viewed through the windshield. Kelley, et al. (1961) tested this possibility by constructing a horizon display that subtended 67° of visual angle. The experimental results showed that the display size was not enough to prevent the subjects from making inappropriate responses. Kelley (1968) concluded that "when the visual display cannot be made as large and compelling as the pilot's view through the canopy or say, Cinerama, then motion compatibility problems arise, and serious consideration should be given to alternative means for presenting the required information" (pp. 98-99). Although alternative avenues are being investigated, the problem of motion compatibility is yet to be resolved.

Effects of Motion on Operator Performance and Training

The preceding review has shown that the task of an aircraft pilot demands that all his sensory and motor capacities be brought to bear on the problem of adapting to his environment. While both visual and proprioceptive inputs are important, ordinarily the former yields sufficient information to allow the pilot to maneuver his aircraft. In fact, traditional formal pilot training programs have operated on the philosophy that proprioceptive cues be ignored and that pilots learn to rely entirely on their instruments to overcome false sensations. This philosophy led to the design and development of fixed-based simulators for training. In a review of the benefits of motion in training simulators, Cohen (1970) emphasized that motion is an important source of information to pilots. According to Cohen motion results in

(1) shorter reaction times, (2) compelling cues that require less attention than visual ones, and (3) decreased lag in comparison to instruments.

Other factors important to the issues of simulation in general and to issues of motion in particular were emphasized in a recent review reported by Williges, Roscoe, and Williges (1973). One factor deals with the degree of simulation. Of concern here is whether the simulator should contain most major features of the actual aircraft, including motion, extracockpit visual cues, etc. The second factor deals with the fidelity of simulation. Assuming that certain features of the aircraft are to be simulated in the trainer, it is important to determine the accuracy with which these features must duplicate the real aircraft. High fidelity is usually emphasized to insure maximum transfer of training from the simulator to the aircraft.

The present discussion is primarily concerned with the use of motion as a means to enhance realism and with certain aspects of motion that appear to be important to training. It must be pointed out, however, that it is not possible to simulate faithfully all motion functions of an aircraft. An aircraft moves in six degrees of freedom, three of which are translational (longitudinal, lateral, and vertical) and the other three angular (pitch, roll, and yaw). Cohen (1970) stated: "To produce the sensation of miles of aircraft motion with a few feet of simulator motion requires consideration of various aspects of human sensitivity to motion" (p. 75). Furthermore, Cohen emphasized that it is essential that research be conducted to determine what kinds

and what degrees of motion are essential to training and Williges, et al. (1973) concluded that "An initial effect in this regard might be to determine what aspects of motion a pilot can perceive and how acceleration thresholds vary under stress. Obviously, if certain types of motion cues cannot be perceived by the human operator, providing them is, at best wasteful" (pp. 550-551).

In the past two decades there have been few systematic attempts to investigate the advantages and disadvantages of motion-based training simulators. Most of these studies have compared human performance under motion and no motion conditions, but few report criterion measures gathered from actual flight.

Experimental evidence that performance improves when motion cues are present was reported by Douvillier, Turner, McLean, and Heinle (1960). They compared performance in a tracking task under actual flight, a motionless simulator, and a simulator free to move in pitch and roll. They found that "the results from the moving flight simulator resembled the results from flight much more than did those from the motionless simulator" (p. 1). In a discussion of this and other studies, Rathert, Creer, and Douvillier (1959) and Rathert, Creer, and Sadoff (1961) stated that motion cues are particularly desirable in simulators for systems with sensitive response to control movements. They also concluded that motion helps by facilitating anticipatory responses (i.e., necessary lead compensation) in systems that are unstable or have sluggish controls. Similar conclusions were reached more recently by Young (1967) and Shirley and Young (1968). Supposedly, proprioceptive cues, added to

the visual ones, provide the operator with information he can use to supply lead compensation in systems that are marginally stable or unstable. Easily controlled systems may not require these motion cues.

There have been several studies that investigated the effect of motion in training. Fedderson (1961) compared motion and no motion groups of unskilled subjects in a helicopter simulator. The motion group learned more quickly than the no motion group. When the motion group was transferred to no motion, and the no motion group to motion, the performance of the groups reversed. Furthermore, the motion group never returned to the performance reached prior to transfer. Similar results were reported by Ruocco, Vitale, and Benfari (1965) in a study that compared the performance of pilots in a simulated carrier landing task under motion and no motion conditions. In addition to improving performance significantly, these investigators concluded that under emergency situations (e.g., failure of the pitch stabilization system in which the subject was instructed to switch the system to off) motion served to increase the alertness of the pilot, but did not serve as a source of information on the vehicle dynamics. Finally, Borlace (1967) concluded that the performance of pilots with motion cues present is closer to their performance in actual flight because habit or expectancy patterns are similar. Borlace qualified his recommendations for the use of motion in training simulators by stating that the training task must be analyzed so that the design of the motion simulator be suited to these tasks.

As can be inferred from previous discussions, the effect of motion and no motion on performance depends on the frame of reference adapted by the pilot. Matheny, Dougherty, and Willis (1963) compared artificial horizon and moving airplane attitude displays with and without motion. Motion was found to be an extremely relevant variable to evaluate displays. Without motion, performance was superior with the moving airplane display, but the difference disappeared when motion was introduced to the simulator. In addition, it was found that reaction times to accelerations were shorter with than without motion. When acceleration exceeded 20 degrees per second squared, the difference in reaction time increased. It was claimed that at higher levels of acceleration, the kinesthetic senses received information in advance of that received from the visual sense (i.e., motion served as an alerting cue). Furthermore, it was found that response times for making judgments of direction of acceleration were shorter with than without motion. Accordingly, motion in this experiment served a more useful role than merely an alerting cue.

In any discussion of the relationships between motion and the various types of visual displays, it would be remiss not to mention the work conducted by Roscoe and his colleagues at the Aviation Research Laboratory of the University of Illinois. Most of the studies compared the order of merit among four displays (artificial horizon, moving airplane, kinelog, and frequency separated). Jacobs, et al. (1973) confirmed other studies by demonstrating that motion served to improve the overall performance of experienced pilots. While superiority was

maintained with all types of displays, performance was disproportionately better with a pursuit moving airplane display. More recently, Roscoe and Williges (1975) determined the order of merit among the four displays in an actual flight environment. Non-pilot subjects were tested under various conditions including disturbed tracking and recovery from an unknown attitude. The latter situation involved a conflict of visual and motion cues. The results showed that the frequency separated display provided equivalent performance to that of the artificial horizon display. Under conflict, the frequency separated display resulted in a reduction of errors over the conventional artificial horizon display, but not as much as the moving airplane display. Ince, Williges, and Roscoe (1975) replicated the procedures of this study, but used a ground simulator. Non-pilots were tested under no motion, sustained banking, and motion with normal washout (i.e., after the simulator reaches a steady state of bank, it is returned to a level position with subthreshold acceleration). Overall performance was found to be superior with than without motion of either type. Moreover, sustained banking provided inappropriate gravitational forces which interfered with command flight path tracking. The presence of normal washout, however, resulted in reversals to unknown attitudes that approximated those obtained from flight (Roscoe & Williges, 1975). Also, the order of merit of the displays corresponded more closely to the order of merit under flight conditions when the simulator operated with washout motion in disturbed attitude tracking and in recovery from unknown attitudes. Finally, an investigation reported by Beringer, Williges, and Roscoe (1975) attempted to determine

whether the adoption of frequency separated attitude displays would have adverse effects on the over-learned response tendencies of pilots. Pilots were tested in a ground simulator first and then transferred to actual flight, using artificial horizon, moving airplane, and frequency separated attitude displays in both. It was found that in disturbed tracking the frequency separated display was superior to the artificial horizon and moving airplane displays during flight. Both the frequency separated and artificial horizon displays resulted in better performance than the moving airplane display in speed of recovery from unknown attitudes in the airplane. When this and the other studies of the Illinois group were compared, the investigators concluded that non-pilots and pilots with little experience can learn to use the frequency separated display without the tendency of making reversal errors that are relatively common with the artificial horizon display. Also, experienced pilots adapted to the frequency separated display without difficulty. This was attributed to the fact that this display is quite similar to the conventional ones.

Another conclusion reached by the University of Illinois investigators was that care must be taken when generalizations are made from simulator results where no motion cues are provided or when motion cues are inappropriate to actual flight conditions. The latter (i.e., inappropriate motion) has received minimal systematic attention among investigators. One study (Jacobs & Roscoe, 1975) examined the effects of transfer from a simulator under three conditions of simulated motion: no motion, motion with normal washout in roll, and a washout condition

in which the onset of acceleration was normal but the direction of motion was randomly reversed 50 percent of the time (i.e., the presentation of unreliable directional cues). The purpose of the latter condition was to determine whether motion cues played a directing or simply an alerting role in learning to cope with conflicts. The results showed that normal washout motion yielded greater transfer than randomly reversed motion, and slightly greater than no motion. It is of interest to note, however, that of the subjects who experienced the random motion condition, none recalled that the motion had seemed strange. Accordingly, the results appear to be somewhat inconclusive with regard to whether motion provided directional or merely alerting cues. On the one hand transfer was slightly better with normal washout, but on the other hand the subjects in the random motion condition were unaware that there was something strange about the motion during training.

Other studies have investigated the effect of non-task related spurious angular accelerations frequently encountered in moving-base simulators. Guercio and Wall (1972) found that the presence of various levels of spurious motion results in higher pilot tracking error, even though pilots are trained to ignore motion. Beck (1974) found that pilot errors increased with increasing levels of spurious motion, but also reported that pilots learned to compensate for these motions. Also, both of these studies found that performance was superior with congruent visual-motion relationships than with no motion.

It can be concluded that the relationships between visual and motion cues in spatial orientation are highly complex. The University of Illinois group and other investigators have shown that performance

not only depends on motion, but on the type and dynamics of the motion. It is obvious that gravitational cues are extremely compelling and cannot be ignored easily. Perhaps the word ignore in this context is inappropriate. The effects may well depend on other factors yet to be investigated or on factors that have received minimal study. Benfari and Vitale (1965), for example, found that pilots could be classified into two groups: those that were "body-oriented" and those that were "frame-oriented." While both groups performed a tracking task better with motion, the body-oriented subjects produced lower mean error. They concluded that frame-oriented pilots were unduly influenced by visual factors, such as the frame of the display, which they interpreted to be vertical and attempted to align it with the horizon. It was suggested that the difference between the two groups may have been due to the effects of pilot training procedures or to selective factors.

Problem

The studies presented in the preceding review were concerned with visual and gravitational factors of spatial orientation while subjects were stationary or while they were exposed to accelerations that could result in momentary conflicts. The purpose of the experiment to be reported herein is to investigate operator tracking performance in an environment that is highly conducive to visual-proprioceptive conflicts.

The experimental scenario is described as follows: An operator is asked to maneuver a remotely piloted vehicle from an airborne control station. This station contains a television monitor, an attitude

control stick and other controls and displays necessary to maneuver the vehicle through a specified course. The vehicle, containing a television camera mounted in its nose, relays an image to be displayed on the television monitor in the control station. Accordingly, the scene displayed to the operator represents the scene viewed by the camera. The task of the operator is to use the instruments, controls, and video display to "fly" the remotely piloted vehicle in much the same way as he would fly any aircraft. This scenario is complicated by several factors. First, the visual inputs received from the vehicle are independent of the proprioceptive inputs received from the airborne station. Second, while pilots are trained to disregard the effects of motion, the research has shown that gravitational cues are extremely compelling and cannot be easily ignored. This assertion is supported by the literature reviewed previously which demonstrated that simulation fidelity is lost whenever fixed-base systems are used for pilot training. Thus, if the airborne station and the vehicle are under turbulence, the stereotypic responses of the pilots will not apply and may even interfere with their performance unless motion cues are totally disregarded.

In the experiment presented here, groups of subjects representing three levels of experience were asked to maneuver a simulated remotely piloted vehicle through a specified course. The subjects sat on a moving base platform designed specifically to simulate the environment of an airborne station (henceforth referred to as the operator station). This station contained a television monitor that provided visual scenes representing those viewed by the remotely piloted vehicle. The flight

path flown by this simulated vehicle was commensurate with the control inputs provided by the subject.

Since the operator station motion was independent of the visual system, it was possible to simulate conditions in which the vehicle only (i.e., the visual input), the operator station only (i.e., the motion input) or both simultaneously were under clear air turbulence. As the subjects maneuvered the simulated vehicle over a series of ground targets, in a task analogous to contact flying, they were introduced at random intervals with stimuli representing the effects of gusts on the operator station and/or the vehicle. The subjects were instructed to null the effects of gusts on the vehicle.

The experiment was designed to answer questions of practical as well as of theoretical significance. A major objective was to compare the effects of visual-proprioceptive conflict on the performance of subjects who have had extensive experience with tracking under various conditions of "task related" motion (i.e., pilots) with subjects who have had experience with tracking and have been exposed to motion but whose task is unrelated to motion (i.e., navigators) and subjects who have had experience with neither tracking nor motion (i.e., inexperienced subjects). It should be pointed out that the important distinction between levels of experience is dependent on the assumption that motion contributes to the performance of certain types of tasks such as flying an aircraft (i.e., is task related), but not to others, such as navigation.

In a between groups design, subjects representing each level of experience were tested in one of four experimental conditions:

(1) Visual only (VO) in which the vehicle was represented as being in turbulence; (2) motion only (MO) in which the operator station was represented as being in turbulence; (3) single axis incompatible (SAI) in which both were under simulated turbulence, but the visual and motion inputs to the subject were incompatible with normal flying conditions (e.g., a visual pitch up was coupled simultaneously with a pitch down motion); (4) single axis compatible (SAC) in which both were under simulated turbulence, but the visual and motion inputs were compatible with normal flying conditions (e.g., a visual pitch up was coupled with a pitch up motion). A fifth condition, double axis incompatible (DAI), experienced by pilots only, represented the situation in which both the operator station and the vehicle were under turbulence, but the visual and motion inputs were incompatible with regard to axis (e.g., a visual pitch up could be coupled with a roll right or left motion, but not pitch).

Four computed measures of performance were utilized: response time (RT), movement rate (MR) of stick deflection following the onset of a response, amendment time to errors, and error rate. The experiment was designed to examine the effects due to compatibility (i.e., conditions), experience, practice, axis of the stimulus, and feedback.

The four major conditions presented above were chosen on the assumption that they differed in their potential to produce visual-proprioceptive conflict. Likewise, the presence or absence of motion was expected to result in differential levels of interference with the subject's learned response tendencies to visual stimuli (i.e., motion compatibility). Thus, if a subject was unable to disregard the effects

of motion in the SAI condition (i.e., the subject used motion as an alerting cue and as a cue to directionality of the visual stimulus), the resultant response (measured as a control stick deflection) would be in the wrong direction (i.e., a reversal error). On the other hand, if the subjects were fully able to disregard motion no differences would be expected among conditions and no responses would be anticipated to motion in MO. Error responses in the VQ condition, with none in SAC, would mean that the absence of motion cues interfered with performance. If SAC and VO result in equally low number of errors, it could be assumed that motion played no useful role in SAC. If both of these conditions result in equally high errors, then it could be concluded that motion did not play a role in SAC and that the required stick deflections to visual displacements (i.e., gusts) were in fact incompatible with the subject's response tendencies (i.e., the video presentation is regarded as an inside-out display). Finally, if RTs in SAC are shorter than in VO, but the number of errors is equal in both, it could be concluded that motion provided an alerting function only. From the literature reviewed previously, it was anticipated that motion in SAC would result in both shorter RTs and fewer errors than VO with motion serving a dual role of alerting the subject to changes in attitude and providing information on the direction of these changes.

It was anticipated that the visual-proprioceptive conflicts produced by SAI would result in a greater number of reversal errors in that condition than in VO and SAC. The fifth condition, DAI, was added to this experiment to lend further support to the prediction that errors in SAI were produced by conflict and were not the result of random

stick deflections. In other words, if motion provides alerting cues and cues to directionality and the subject does respond to these cues, then the error deflections should be commensurate with the motion function. Since the motion stimulus in DAI was on a different axis from the stimulus presented visually, this condition was expected to result in a high proportion of axis errors, rather than reversal errors.

In this experiment, the direction of displacement of the visual scene presented on the television monitor remained unaltered with respect to the direction of stick deflection. In all experimental conditions this relationship (referred to as motion compatibility in the review) was commensurate with normal flying operations. The difference between the experimental conditions was the presence or absence of motion and the axis and direction of the motion with respect to visual displacement. If a pilot's response tendencies are dependent on motion cues (i.e., the pilot uses rather than disregards motion), then a motion function which is in conflict with these old and over-learned habits should interfere with his performance. Accordingly, it was anticipated that pilot performance, as reflected by reversal and axis errors, would be poorer in SAI and DAI than SAC. Also, the absence of motion in VO was expected to reduce pilot performance as compared to SAC. If performance in SAC is dependent upon learned habits peculiar to pilots, then the performance of non-pilots should be worse than that of pilots in this condition. In fact, if pilots have learned to use motion cues and it is assumed that non-pilots have not, then non-pilots should show no effect due to conditions (i.e., the differing potential of each condition to produce conflict should have no effect on the

non-pilots). A significant effect favoring pilots in all conditions could be predicated on the assumption that previous exposure to flight conditions would aid them in overcoming inappropriate responses due to conflicting cues (Kelley, et al., 1961). The review of the literature, however, suggested that visual-motion relationships in SAI should have a profound negative effect on the performance of pilots and to a lesser degree on non-pilots. While navigators have had experience with tracking tasks in which motion is non-task related, the performance of this group should be similar to that of the inexperienced subjects.

The assumptions discussed in the preceding paragraph are relevant also to RT measures. If motion provides anticipatory (i.e., alerting) cues, then RT should be shorter with motion than without (Cohen, 1970; Matheny, et al., 1963). This prediction can be generalized to subjects in all experience groups. The past experience of pilots, however, should favor this group over non-pilots. Finally, since navigators have had experience with tracking tasks, RT in this group should be shorter than that of the inexperienced subjects.

It has been found repeatedly that responses to visually displayed roll result in more errors than to pitch (Kelley, 1968; Kelley, et al., 1961). It was anticipated that these same results would be obtained in this experiment, regardless of condition or experience group. Similarly, RTs to visually presented pitch should be shorter than to roll (the oblique effect).

The effect of practice (learning) in the experimental task should be evidenced primarily in those conditions conducive to visual-proprioceptive conflict (i.e., the conditions that are predicted to

result in the largest number of control errors). Similarly, since a greater number of errors was anticipated from roll axis stimuli, the effect of practice should be evident primarily in roll. Finally, if SAI produces the largest number of errors as well as the largest effect due to practice, it can be assumed that the subjects (but primarily the pilots) were able to learn to disregard motion or to adopt new response tendencies.

The experiment was designed also to determine whether the effect of conflict is carried to control movements following the onset of the response (i.e., beyond the point where RT is computed). In addition to simple counts of directional errors, the MR of correct and error responses, as well as RT and MR to the correction of errors, was computed. While the analysis of these data was primarily for exploratory purposes, it was anticipated that the effect of visual-proprioceptive conflict would be observed in the RT measures. Once an error has been executed and detected under conditions of conflict, the correction of this error should proceed in a fashion similar to that of a correct response.

Finally, a post hoc analysis of RT on errors and error correction was conducted to determine the possible effect (if any) of visual feedback on the detection of errors. In a previous investigation reported by Gibbs (1965), it was shown that errors produced by incompatible control-display relations can be corrected in a temporal period shorter than that required for visual feedback. The present experiment was well suited to test this possibility.

EXPERIMENTAL PROCEDURE

An experiment was designed and conducted to assess the effects of visual-proprioceptive cue conflicts on human performance. The experimental procedure discussed below is organized into two major topic areas. The first is devoted to a general review of the method and includes a description of the equipment, tasks, conditions, and subjects utilized. It also provides a detailed coverage of the experimental design and steps employed in the execution of the research. The second topic is concerned with performance measures. Included is a discussion of the techniques employed to acquire data and to derive computed measures of performance from these data. A preliminary investigation was carried out to assess the suitability of the overall experimental configuration, including the equipment, tasks, procedures, and performance measures. The method and results of this investigation are presented in Appendix A.

Method

Apparatus

The equipment used in this experiment consisted of an operator station mounted on a motion platform, hydraulic pump, terrain model, television camera and optical probe, experimenter station, and a Sigma 5 digital computer. The operator station was designed specifically to simulate the environment of an airborne control station. This station

contained a television monitor, which provided visual images relayed to it from a simulated remotely piloted vehicle. The visual images were generated by the television camera and optical probe, which viewed the terrain model. The path followed by the camera and probe over the terrain model was commensurate with the vehicle flight path as determined by the control stick inputs provided by the subject. Since the control stick and visual system were independent of the motion platform, the capability existed for the subject to maneuver the simulated remotely piloted vehicle under various environmental conditions. This arrangement permitted the introduction of conditions in which the vehicle alone, the airborne station alone, or both, were under clear air turbulence. A brief description of the hardware systems is presented below.

Motion system. The motion system provided onset cues in two degrees of freedom of angular acceleration. Roll onset cues were provided by tilting the simulator about the longitudinal axis (i.e., the X axis) and pitch onset cues were provided by tilting the simulator about the lateral axis (i.e., the Y axis). Excursion of the simulator was restored to a neutral (level) position by motion in the opposite direction. Motion was achieved by the actuation of hydraulic cylinders mounted under a 9 by 8 ft. (2.74 by 2.4 m) simulator platform as shown in Figure 1. Actuation of the center cylinder, located 18.5 in. (47 cm) forward of the operator's seat reference point (i.e., the point where the middle lines of the seat--the centerline of the platform--and the back rest intersect) provided motion in the pitch axis. The second cylinder, located 19.5 in. (49.5 cm) behind the operator seat reference point, remained fixed. Actuation of

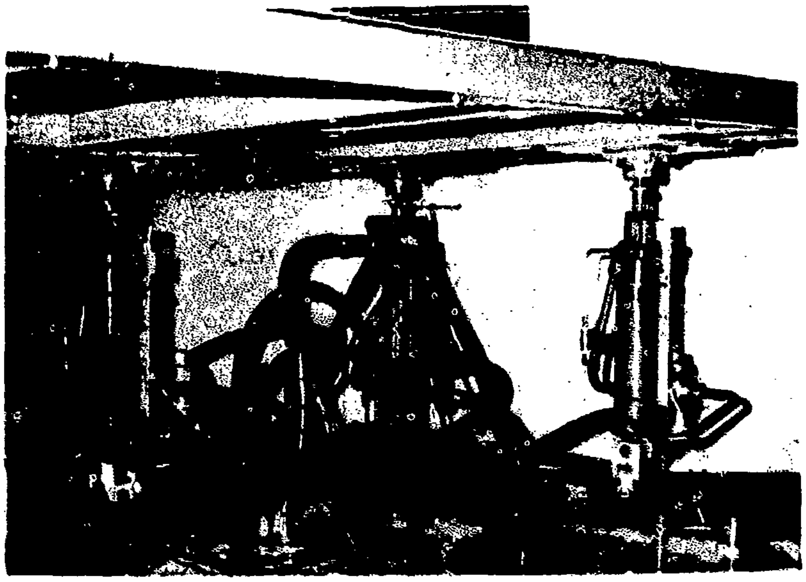

Figure 1. Motion platform and hydraulic cylinders.

the third cylinder, located 30 in. (76.2 cm) to the left of the second cylinder, provided motion in the roll axis. The direction of flow of hydraulic fluid in the cylinders depended upon the actuation of hydraulic valves. Pressure against a piston in the cylinder moved the platform in the appropriate axis. Actuation of the valves was achieved by manual input from the experimenter station, but under computer control. Executive routines determined what axis-direction combination had been selected and provided a command for the actuation of the appropriate hydraulic valve.

Finally, an hydraulic pump provided constant pressure (1500 psi) to the control valves. Switches to limit the excursions of the platform were mounted on the system to protect the subjects, experimenters, and other personnel and equipment against possible hardware malfunctions. These switches actuated an electronically operated hydraulic pressure

valve, which removed pressure from the cylinder valves and allowed the platform to settle to a safe condition.

Visual system. The visual system consisted of a terrain model, television camera and optical probe, and three monochromatic television monitors (modified SMK-23 Visual Simulator, The Singer Company). A three dimensional terrain model provided major "real world" ground cues for visual contact tracking over the surface. Included on the terrain model were flat lands, mountains, rivers, towns, trees, roads, etc. The real world to terrain model scale was 3000:1 and represented a six by twelve mile area. The model was mounted on an endless belt that was servo driven to represent visually the continuous changes in the scene as the simulated remotely piloted vehicle traveled along the north-south direction. A television camera viewed the terrain model through an optical probe (see Figure 2) that contained a servoed mechanical assembly to permit the introduction of heading, roll, and pitch. Both the camera

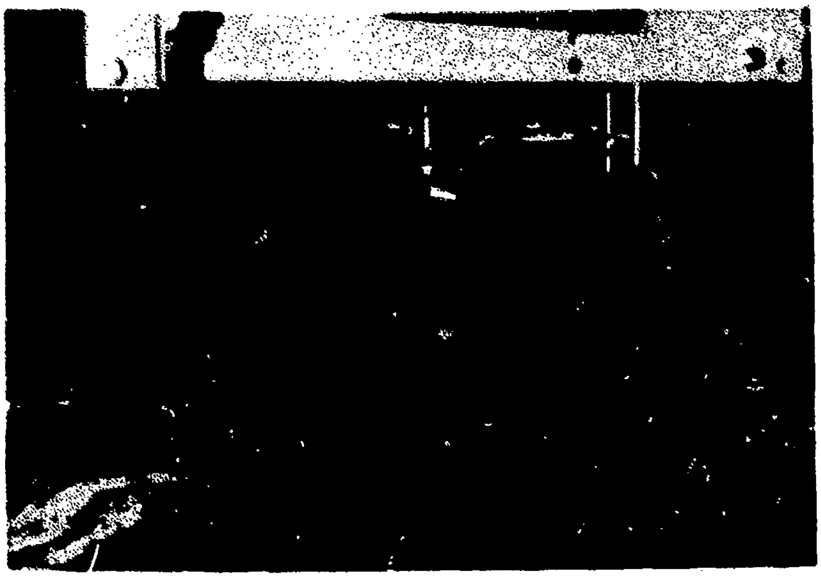

Figure 2. Optical probe.

and the optical probe were mounted on a servo driven carriage system (see Figure 3) that moved across the terrain model to simulate movement along east-west directions, and in and out to simulate altitude changes. The path followed by the television camera/terrain model combination was commensurate with the actual path of the simulated vehicle as determined by control inputs provided by the subject. The three television monitors presented the scene viewed by the optical system. The field of view represented on the television monitors subtended a viewing angle of 50° horizontally and 38° vertically over the terrain model. One television

Figure 3. Television camera and carriage system.

monitor was mounted in the operator station and the other two were located at the experimenter station. All three monitors had a 1000 line resolution vertically.

Operator station. The operator station, shown in Figure 4, consisted of a Conrac television monitor (Model COC-17), attitude director indicator, altitude indicator, an amber colored altitude warning light, and a side-arm rate control stick. The subject sat in an aircraft type seat directly facing a 14 by 11 in. (35.6 by 27.9 cm) television monitor mounted in a center panel. The monitor was approximately perpendicular to the subject's line of sight, with the top inclined 12 degrees from

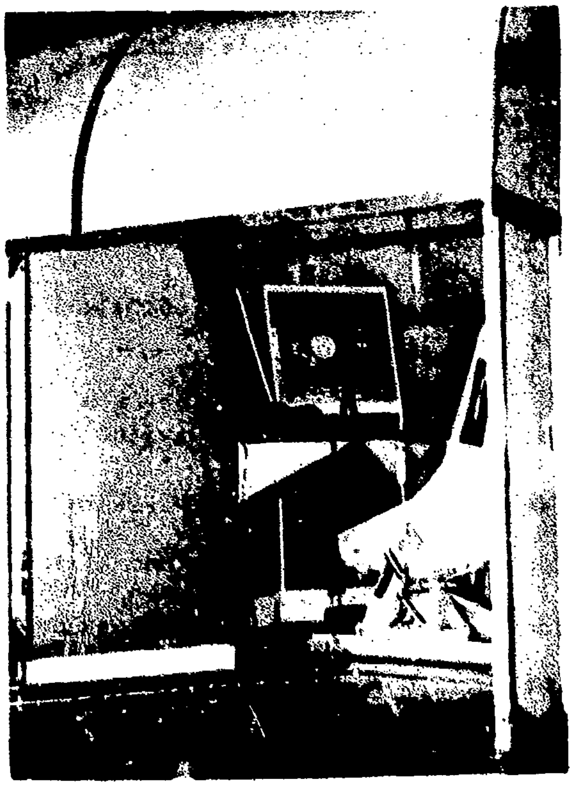

Figure 4. Operator station mounted on the motion platform shown in Figure 3. (The display shown on the right panel was not used.)

the vertical, away from the subject. The distance between the subject's eyes and the center of the television screen was 28 in. (71.1 cm). The viewing angle subtended 28.07° in the lateral plane and 22.23° in the vertical plane of the monitor. The altimeter, altitude warning light, and the attitude director indicator were mounted on a flat sectional panel to the left of the subject and at an angle of 45° from the center panel, as shown in Figure 5. The altitude warning light was located 45° from the subject's line of sight. The altimeter, mounted 1.5 in. (3.8 cm) under the warning light, was a vertical straight scaled indicator with a moving pointer to provide altitude readings in feet above sea level. A 6 in. (15.2 cm) side-arm rate control stick was mounted on the right hand display console armrest as shown in Figure 6. The control stick was spring-centered with a dual-axis (free positioning) capability that required 4 oz. (113.4 g) breakout force. This same amount of force was needed to hold the stick at full deflection. The range of deflection on both lateral (right-left) and longitudinal (fore-aft) stick was 0 to 25°.

The operator station contained a foot switch to allow the subject to communicate with the experimenter station personnel. Depression of this switch activated a lip microphone attached to the headset. White noise (Gaussian Noise Generator, Model 311A, Elgenco, Inc.) was input to the headset to mask external disturbances. At eye level, the incident illumination was .37 footcandles as measured with the Spectra Illumination Meter (Model FC 200 TV-B). The aircraft seat was equipped with a standard shoulder harness and lapbelt to protect the subject.

Figure 5. Operator station instruments.

Figure 6. Side arm control stick and television monitor.

This restraint system was necessary because the subject was to be tested under conditions of simulated gust turbulence. Finally, an air conditioner maintained the operator station temperature at 70°F (21.1°C).

<u>Experimenter station</u>. The experimenter station contained all the equipment necessary to monitor the status of the hardware/software, the control activities of the subject, and to set up the various stimulus conditions. The configuration of the experimenter station is shown in Figure 7. This station was manned by two individuals; a system manager and an experimenter. The task of the system manager was to prepare the system for operation, insure that all hardware was operating effectively and reliably prior to and during the experiment, set up the conditions for all the experimental trials in accordance with a prepared checklist, and provide the subject with assistance when necessary. Available to the

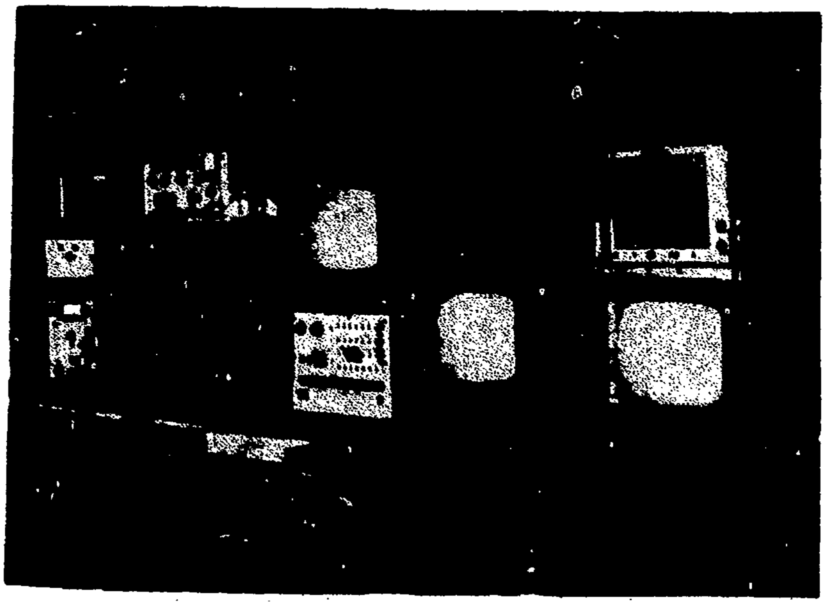

Figure 7. Experimenter station.

system manager were three display monitors. A system status display provided information on hardware/software status, subject identification, and other data on the specific experimental run. This status display was updated continuously so that all system conditions could be monitored during the experiments. Also available to the system manager was a television monitor that displayed the same scene viewed by the subject. A third display presented a continuously updated representation of the subject's ground track. By monitoring these displays, the system manager could determine whether the subject and/or the system had generated a condition serious enough to abort an experimental run. A communication system allowed the system manager to converse with the subject and with personnel in the computer facility.

In addition to the displays discussed above, the system manager was provided with discrete switches to enter the subject's identification number and other pertinent information in computer core, to initiate and terminate experimental runs, and to set up the visual-motion stimulus combinations for input by the experimenter.

The second position, manned by the experimenter, was provided with two display monitors in addition to the status and ground track displays, which were shared with the system manager. One of these displays presented the same scene viewed by the subject and the other presented the subject's stick position in percent deflection. Taken together, these displays were used by the experimenter to determine the appropriate conditions for introducing a stimulus to the subject. Once the system manager had set up a specific stimulus combination and the conditions

were determined to be appropriate, the experimenter pressed a discrete hand-held insert button to initiate a trial stimulus. More will be said about the functions of the experimenter and the conditions necessary to present stimuli in the Procedures.

Computer system and interfaces. A Sigma 5 digital computer was used to drive the peripheral equipment discussed above and to record data during the experimental runs. The block diagram in Figure 8 presents the complete simulator system. Real-time computer programs were stored on a random access disk to provide rapid load capability. In preparation for experimental runs the programs were transferred from the random access disk to core memory. The input/output processor managed the data transfer to and from the peripheral devices. The system interface contained analog to digital and digital to analog converters and discrete input/output equipment. This interface operated as an on-line peripheral to the computer. All analog signals from the peripheral devices and all the digital data from the computer were converted and transferred by this interface system.

Resident software consisted of a real time aerodynamic mathematical model, executive routine, and data recording programs. The mathematical model was a six degree of freedom simulation of a fixed wing aircraft used to represent a remotely piloted vehicle. This model received inputs from the subject's control stick and provided outputs to drive the camera and probe to produce the proper visual image as well as other data necessary to drive the flight related displays at the experimenter and operator stations. The executive routine served as software

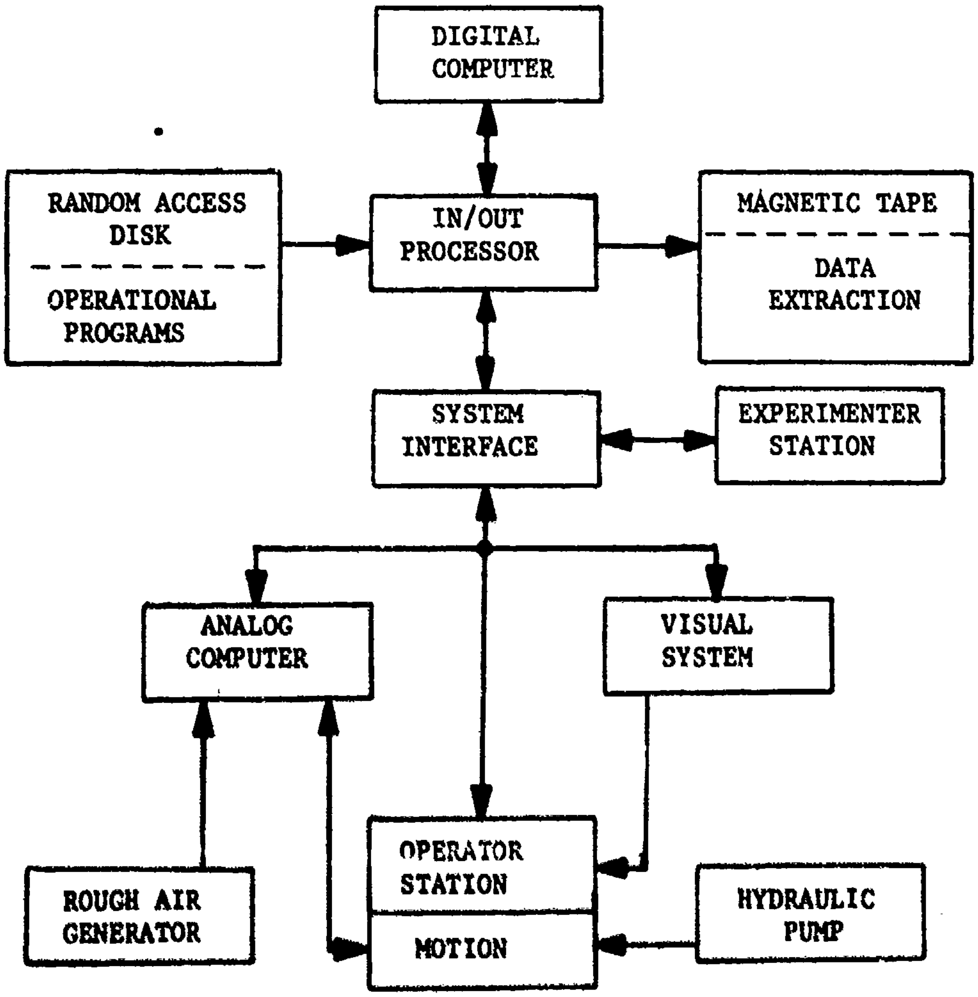

Figure 8. Block diagram of the simulation system.

interface between the experimenter station and the mathematical model and motion platform by producing stimuli (i.e., inserting forcing functions) when commanded. Depending on switch settings at the experimenter station, visual and/or motion stimuli were produced by emulating a sudden change in roll or pitch similar to that produced by a sharp wind gust. Actual activation of visual stimuli was accomplished by adding a predetermined value to the sampled stick value and sending that sum to the mathematical model in lieu of sending the actual stick position over the fixed number of program cycles. This proved to be a simple and effective method of producing realistic visual stimuli. When a motion stimulus was required, the necessary forcing function, programmed on the analog computer, was triggered under control of the executive routine. Data recording programs recorded all required measures on 9-track magnetic tape, inserted header information used to identify experimental runs and trials, and produced some on-line plots and computed values necessary for the conduct of the experiment.

The analog computer was used primarily to control the motion platform. This included continual generation of low amplitude inputs on both roll and pitch axes to simulate rough air and, thereby, add realism to the task.

Training and Experimental Tasks

The training and experimental tasks consisted of maneuvering a simulated remotely piloted vehicle through a specific tracking course. This was a form of contact flying operation that required the subject to track ground targets and to maintain a level horizon (i.e., maintain

the remotely piloted vehicle wings level). Since scaled references were not provided on the television monitor, the task consisted of subjective compensatory tracking. Thus, the point where a displayed error (e.g., the remotely piloted vehicle wings not level) was nulled (i.e., to wings level), depended on a subjective estimation made by the subject. Easily visible ground targets were numbered and placed on the terrain model at intervals approximating a representation of two statute miles (3.2 km) (see illustration on page 68). There were ten targets, five on the right-hand side (east) and five on the left-hand side (west) of the terrain model. The five targets spaced on the east side of the model, were numbered sequentially towards the northern region of the model. Similarly, the other five targets were numbered sequentially, but spaced at intervals from north to south, down the west side of the model. This arrangement of targets resulted in the most efficient use of the terrain model. The average height of the targets represented approximately 200 ft. (60.96 m) from the ground and their width represented 125 ft. (38.1 m). The targets were placed perpendicular to the terrain model for maximum visibility.

In addition to the spacing of targets discussed above, the targets were alternated laterally, left and right, at distances representing about .12 of a mile (.19 km) from the centerline between targets. This arrangement required that the subjects make heading corrections as the simulated remotely piloted vehicle was flown towards each target. The subject was asked to maneuver the vehicle over a target and then apply the necessary corrections to acquire the next target. As a "fly-over" occurred, the target would leave the field of view at the bottom of the

television screen and the next target would appear over the horizon to the left or right of the current heading. Heading corrections to the target were made at this point. This process was repeated until the subject had tracked the vehicle over the fifth target, upon which he was instructed to bank the vehicle to the left in order to acquire the sixth target. Arrows, strategically placed on the terrain model, aided the subject in making the turn for a heading due south. Target tracking continued until the last target had been reached. The simulated vehicle was flown at an average airspeed of 150 knots and at an altitude between 180 and 1000 ft. (54.9 and 304.8 m). The warning light flashed whenever the simulated vehicle reached a level below 180 ft. and remained on whenever 1000 ft. was exceeded. In these cases, the subject was instructed to pitch up or down to maintain the required altitude limits. The average tracking time over all ten targets was 6 min. 30 sec. and ranged from 6 min. 8 sec. to 6 min. 53 sec. One complete flight over the ten targets covered approximately twenty statute miles around the terrain model.

Training task. This task consisted of tracking the ten targets as described in the preceding paragraph. The attitude director indicator was activated during training to aid the subject in learning the control-display relations. Motion was not provided in this session.

Experimental task. The experimental task was identical to the training task except that the subjects were presented stimuli that simulated clear air turbulence in the form of gusts. As will be recalled, the tasks to be performed by the subjects were those required to control a remotely piloted vehicle containing a television camera mounted in its

nose. Since the activities were performed from a simulated airborne control station, various combinations of visual and motion displacements were possible (i.e., visual and/or motion machine outputs). Upon the presentation of a stimulus, the subject responded with an appropriate control stick maneuver to null the effects of gusts.

The introduction of a simulated gust on the television monitor and/or motion constituted a single experimental trial. The visual stimuli were viewed by the subjects as angular displacements of the terrain. Figure 9 is a photographic representation of level flying as the remotely piloted vehicle approaches the fourth target. Figures 10 and 11 illustrate the effects due to the introduction of left and right roll stimuli, respectively. These visual displacements were similar to

Figure 9. Illustration of the terrain as viewed by the subject during level flight.

Figure 10. Illustration of a roll to the left due to the introduction of a stimulus.

Figure 11. Illustration of a roll to the right due to the introduction of a stimulus.

those encountered in contact flying conditions. Thus, a right roll was observed on the television monitor as a counterclockwise angular displacement of the terrain. A left roll was observed as a clockwise angular displacement. Similarly, a pitch up was associated with a downward displacement of the terrain and pitch down with an upward displacement.

The visual stimulus (or input error due to simulated gusts) duration was one second and the displacement was ±18°/sec. on roll and pitch during the initial .5 sec. and ±21°/sec. on roll and ±14°/sec. on pitch during the remaining .5 sec. Any control stick activity occurring during this period either increased or decreased the rate of error. If, for example, the subject was in the process of making a heading correction by deflecting the stick to the right at the time that a right roll stimulus was presented to him, the rate of displacement (right bank error) would increase accordingly. On the other hand, if the subject was making a left bank the rate of displacement would decrease or be nulled. Accordingly, it was important that all stimuli be presented during periods in which the subject was not actively engaged in making corrections and that the attitude of the vehicle be within prescribed limits. The method used to insure that stimuli were presented under proper conditions is discussed in the Procedures. Finally, if no corrective input was provided by the subject in response to a stimulus, the maximum displacement was limited under software control to ±21° on roll and ±14° on pitch.

As noted earlier, motion stimuli were provided by tilting the motion platform about the longitudinal axis (roll) or the lateral axis

(pitch). After reaching full excursion, the motion platform was restored to a level position by motion in the opposite direction. Return of the platform to a level position, however, did not involve a motion washout function below sensory threshold. Although such functions are used in pilot training simulators to eliminate uncorrelated visual-motion cues, the environment simulated in the experiment required that motion be independent of the operator's control activities. This arrangement was necessary because in an operational environment the airborne control station is flown by a pilot and not the remotely piloted vehicle operator. Since the turbulence affecting the station was always in the form of gusts (simulated as motion), it was assumed that the pilot would immediately restore the station to a level condition. Such an environment rendered washout unnecessary, if not unrealistic. Thus, after reaching maximum excursion in one second, the motion platform was restored to a level position in an equal amount of time. Maximum excursion on all experimental trials was limited to ±8° on roll and ±7° on pitch. Since the seat reference point was 18.5 in. (47 cm) behind the center cylinder and 8.75 in. (22.2 cm) above the point of platform rotation, the vertical excursion at this reference point was 2.4 in. (6.10 cm) for pitch and the lateral excursion was 2.0 in. (7.37 cm) for roll.

Experimental Conditions

The five experimental conditions are presented in Table 1. An examination of this table will show that the conditions represented various visual-motion stimulus combinations existing between the simulated airborne control station and the remotely piloted vehicle. Also shown in the table are the directions of the visual-motion displacements in each condition. Figure 12 exemplifies the visual-motion stimulus combinations in each of the five conditions. A brief description of the conditions follows:

Visual only (VO). Stimulus presentation was limited to the visual system. This condition simulated the environment in which the remotely piloted vehicle was in turbulent weather, but the airborne control station was not (see Figure 12b).

Motion only (MO). Stimuli were introduced through the motion system only. This condition simulated the situation in which the airborne control station was in turbulent weather, but the remotely piloted vehicle was not (see Figure 12c). Any responses to trials in this condition introduced error where none existed.

Single axis incompatible (SAI). Visual-motion combinations were presented simultaneously but were in conflict with respect to direction of displacement. This condition simulated the situation in which both the airborne control station and the remotely piloted vehicle were in turbulent weather. The direction of visual displacement, however, was in conflict with normal contact flying conditions. Thus, for example, a roll motion to the right would be coupled with a visual roll to the left (see Figure 12d). The appropriate response, of course, was a

TABLE 1

Visual-Motion Stimulus Combinations Used in Each Experimental Condition

Experimental Conditions	Visual Stimulus (Axis and Direction of Displacement)	Motion Stimulus (Axis and Direction of Displacement)
Visual Only (VO)	Pitch Up	0
	Pitch Down	0
	Roll Right	0
	Roll Left	0
Motion Only (MO)	0	Pitch Up
	0	Pitch Down
	0	Roll Right
	0	Roll Left
Single Axis Incompatible (SAI)	Pitch Up	Pitch Down
	Pitch Down	Pitch Up
	Roll Right	Roll Left
	Roll Left	Roll Right
Single Axis Compatible (SAC)	Pitch Up	Pitch Up
	Pitch Down	Pitch Down
	Roll Right	Roll Right
	Roll Left	Roll Left
Double Axis Incompatible (DAI)	Pitch Up	Roll Right
	Pitch Up	Roll Left
	Pitch Down	Roll Right
	Pitch Down	Roll Left
	Roll Right	Pitch Up
	Roll Right	Pitch Down
	Roll Left	Pitch Up
	Roll Left	Pitch Down

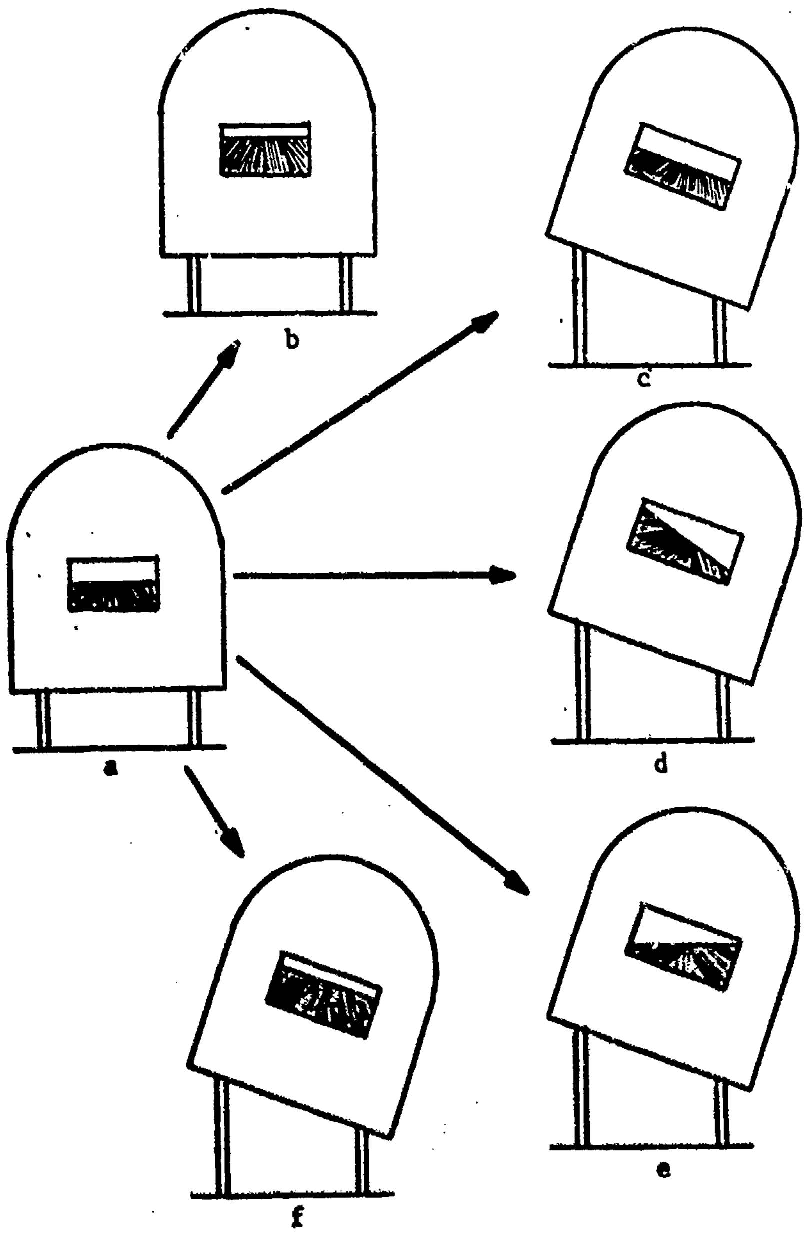

Figure 12. Visual-motion relationships prior to the introduction of a stimulus (a) and on each of the five experimental conditions: (b) VO, (c) MO, (d) SAI, (e) SAC, (f) DAI.

control stick deflection to the right to null the effect produced by the left bank error. A control stick deflection to the left would result in a control reversal and increase the left bank error rather than reduce it.

Single axis compatible (SAC). Visual-motion stimulus combinations were presented simultaneously, but were not in conflict with respect to direction of displacement and axis. This condition simulated the situation in which both the remotely piloted vehicle and the airborne control station were in turbulent weather, but the visual-motion relationships were compatible with normal contact flying conditions. Thus, a roll motion to the right would be coupled with a visual roll right (see Figure 12e). The appropriate response was a control stick deflection to the left. A stick deflection to the right resulted in a control reversal.

Double axis incompatible (DAI). Visual-motion stimulus combinations were presented simultaneously, but were in conflict with respect to the axis in which the displacement occurred. This condition simulated the situation in which both the remotely piloted vehicle and the airborne control station were in turbulent weather, but the visual-motion relationships were incompatible with normal contact flying conditions. Thus, for example, a visual pitch down stimulus could be coupled with a roll motion to the right (see Figure 12f). An appropriate response would require an aft control stick deflection to null the error. A control stick deflection to the left would result in an axis error and add roll error to an already existing pitch error.

Subjects

Fifty-two male volunteers, all uniformed members of the United States Air Force, served as subjects in this experiment. These subjects were assigned to one of three experience groups consisting of twenty pilots, sixteen navigators, and sixteen non-rated (inexperienced) officers. The selection of subjects depended on prior experience. It was required that the pilots be on current flying status and that they have had at least 300 hours flying time. It was further required that neither the navigators nor the non-rated participants possess piloting experience. Since the control stick was mounted on the right hand console armrest and the non-rated subjects had no experience with tracking, it was required that these subjects be right handed. Questionnaires designed specifically for each of the three experience groups, were administered to all subjects (see Appendices B, C, and D). Aside from the demographic characteristics on each subject, it was also of interest to obtain other information relevant to the flying experience of pilots and navigators, and any possible informal (i.e., observational) piloting experience possessed by navigators and non-rated participants. Also of interest was information relative to the subjects' susceptibility to motion sickness or disorientation. Appendix E contains a detailed tabulation of questionnaire responses. The general characteristics of each experience group are summarized below.

Pilots. The average age of pilots was 34.5 (median, 34.5) with a range of 26 to 45 years. All pilots possessed at least four years of higher education. The mean number of flying hours was 2,953 (median, 2,924), with a range of 350 to 5,100 hours. The mean number of years

of flying experience was 9.9 (median, 10.25), with a range of 3 to 32 years. Two pilots reported that they had experienced either car or seasickness, but none reported airsickness.

Navigators. The average age of navigators was 33.5 (median, 33.5), with a range of 25 to 44 years. All navigators possessed at least four years of higher education. The mean number of navigation flying hours was 2,531 (median, 2,499), with a range of 620 to 5,700 hours. The mean number of years experience was 8.1 (median, 7.25), with a range of 2.5 to 19 years. Four navigators reported that they had some presolo piloting experience, but in all cases this experience had occurred at least seven years prior to the experiment (the median number of years was 10). Nine navigators had some informal "back seat" or observational experience of piloting tasks. Of these, four reported that they had, on a few occasions, performed some instrument flying. In all cases, however, this experience was minimal. Two navigators reported that they had experienced airsickness and one of these had also experienced seasickness. Two navigators were replaced in the experiment. Both of these subjects tended to overcontrol during the tracking task. In one case, the performance, as measured by percent stick deflection was 5.59 standard deviations above the mean on lateral stick and 3.17 on longitudinal stick. The other subject was 3.64 standard deviations above the mean on lateral stick and 4.25 on longitudinal stick (see Performance Measures for a general description of the meaning of percent control stick activity).

Non-rated. The average age of the non-rated subjects was 31.2 (median, 30.5), with a range of 23 to 44 years. All of these subjects

had completed at least four years of higher education. Two subjects reported that they had some presolo piloting experience, but in both cases, this experience had occurred seven years previously and was of short duration. Three subjects reported some informal observational experience and two had some minimal experience in an aircraft ground simulator. Three non-rated subjects were replaced. It was discovered that one left handed subject had been inadvertently selected to participate. The other two subjects showed poor tracking performance during training and did not improve throughout the experimental sessions. Also, these two subjects needed frequent guidance from the experimenter in all sessions. Two subjects reported that they had experienced air-sickness and one reported that he had experienced seasickness.

Design

The sixteen subjects in each of the three experience groups (pilot, navigator, and non-rated), were assigned randomly to one of four experimental conditions (VO, MO, SAI, and SAC). An additional four pilots were assigned to the DAI condition. It was recognized that the ideal design would require that all subjects be administered all conditions (i.e., a within groups design). This type of design was rejected from consideration for two related reasons. First, the subjects with the required experience (particularly pilots and navigators) are difficult to locate and schedule. Second, and a more compelling reason, was that the relatively large number of conditions in the experiment would create a formidable balancing problem. The strong possibility of asymmetry due to transfer effects (Poulton and Freeman, 1966) in a within groups

design, would require that all combinations of the experimental conditions be administered and examined. Constraints on subject availability rendered this approach impractical, if not impossible.

All subjects served for approximately 45 min. on each of five consecutive days (sessions). The first session was for the purpose of familiarizing the subjects with the equipment and procedures, and for training in the basic tracking task. The experimental tasks were performed in Sessions 2 through 5. As noted earlier, a trial was defined as the introduction of one stimulus during the experimental task. A block of trials consisted of ten stimuli presented during a simulated flight over the ten targets. With the exception of the DAI condition, there were four possible visual and/or motion stimulus combinations associated with each condition (see Table 1), depending upon the direction of displacement on each axis (i.e., pitch up, pitch down, roll right, and roll left). These four stimuli were randomized (without replacement) such that the subject would experience five of each in two consecutive blocks of trials. In addition, four different lists (one for each block) of randomized trials were prepared and all subjects in each group experienced the same sequences. To avoid possible effects due to recall, the order in which the four blocks of trials were presented was randomized on each session, but subjects in each condition were presented the same order. Each subject was given 40 trials per session (10 in each direction of displacement) for a total of 160 trials on all four sessions (40 in each direction of displacement). Thus, the total number of trials for the four subjects in each experimental condition was 640 (160 in each

direction of displacement). Due to equipment problems, a block of trials was not presented to one non-rated subject in VO. Consequently, the total number of trials for that group of four subjects was 630. Appendix F presents a tabulation of the total number of trials and responses.

Unlike the four experimental conditions discussed in the preceding paragraph, the DAI condition was administered to pilots only. As noted in Table 1, there were eight possible visual-motion combinations. These eight stimuli were randomized (without replacement) such that the subject would experience five of each in four consecutive blocks of trials. Four randomized lists (one for each block) were prepared and the four subjects experienced the same sequences. Also, the order of presentation of each block was randomized in each session, but all subjects were given the same order. Each subject was presented with 40 trials per session (five in each visual-motion combination) for a total of 160 in all four sessions (20 in each visual-motion combination). The total number of trials was 640 (80 in each visual-motion combination).

With the exception of the MO and DAI conditions, the experimental design consisted of two factors between groups and three factors within groups. The factors between groups and levels for each were Experience (3) and Experimental Conditions (3). The factors within groups and levels for each were Axis (2), Direction of Visual Displacement (4), and Sessions (4). Since no visual stimuli were presented in the MO condition, the data were treated in a separate analysis.

DAI was compared to the other conditions, but the analysis was limited to the pilot sample only. The design consisted of one factor between groups and three factors within groups. The factor between groups and levels was Conditions (4) and the factors within groups and levels were Sessions (4), Axis (2), and Visual-Motion Combinations (8).

Procedures

Upon arrival for the first session, each subject was asked to read a prepared set of instructions (see Appendix G). The subject was then escorted to the operator station and was seated in front of the television monitor. A short period was dedicated to familiarize the subject with the location of equipment. The experimenter proceeded to demonstrate the training task to better acquaint the subject with the procedures. Emphasis was placed on the corrections necessary to acquire the targets, maintain level flight, and keep the altitude within limits. After a short question and answer period, the subject performed the training task in the presence of the experimenter. Performance data were recorded the moment the subject began tracking. Upon completion of the first training flight over the ten targets, the experimenter left the operator station and assumed his position at the experimenter station. The subject proceeded to complete an additional two training flights with a one minute rest period between each. Any necessary guidance was given to the subject over the communication system. Upon termination of the training session, the subject was provided with a copy of the questionnaire (see Appendices B, C, and D).

In each experimental session, the subjects were again escorted to the operator station and given assistance in adjusting the protective restraints. The experimenter and system manager assumed their position and proceeded to read instructions over the communication system.[2] The instructions varied in accordance with the experimental conditions as follows:

> <u>VO condition</u>. As you fly the remotely piloted vehicle through the same course you have previously, it will encounter clear air gusts. These gusts will be observed on the television display as pitch or roll. Your task will be to level the remotely piloted vehicle as quickly as possible and continue the flight over the various targets. Do you have any questions?
>
> <u>MO condition</u>. As you fly the remotely piloted vehicle through the same course you have previously, the airborne control station, but not the remotely piloted vehicle, will encounter clear air gusts. Your task will be to continue to maneuver the remotely piloted vehicle through the prescribed course. Do you have any questions?
>
> <u>SAI, SAC, and DAI conditions</u>. As you fly the remotely piloted vehicle through the same course you have previously, the remotely piloted vehicle and the airborne control station will encounter clear air gusts occurring simultaneously. These gusts will be observed on the television display as pitch or roll. Your task will be to level the remotely piloted vehicle as quickly as possible and continue the flight over the various targets. Do you have any questions?

The subject was informed that the attitude director indicator was deactivated and that he should focus his attention on the television monitor and not on other indicators. (The flashing or steadily on

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[2]The fundamental issue in this experiment (i.e., visual-proprioceptive conflicts) was explored by analyzing the response characteristics immediately following the introduction of a stimulus rather than by measuring overall tracking performance. To avoid possible variability in the data (i.e., response time) that could result from unspecified set for either speed or accuracy (Fitts, 1966) the instructions given to the subjects emphasized speed.

altitude warning light could be observed easily through peripheral vision.) The simulated rough air and the television monitor were then activated and the subject was asked whether he was ready to begin the task. Upon a ready response from the subject, the system was released from freeze status and the subject began maneuvering activities towards the first target.

The experimental trials were initiated manually from the experimenter station. The system manager set up the conditions for each trial in accordance with the prepared checklist discussed earlier. This process consisted of setting discrete switches to select the visual/motion/axis/direction of displacement combinations for an upcoming trial When all conditions were met, the system manager activated a lamp to advise the experimenter of the system status. It was then the responsibility of the experimenter to determine the appropriate time and condition for presenting the subject with a trial. A decision to initiate a trial required that the experimenter determine whether a set of criteria had been met. The criteria and the displays used to aid the experimenter in making a decision are listed below:

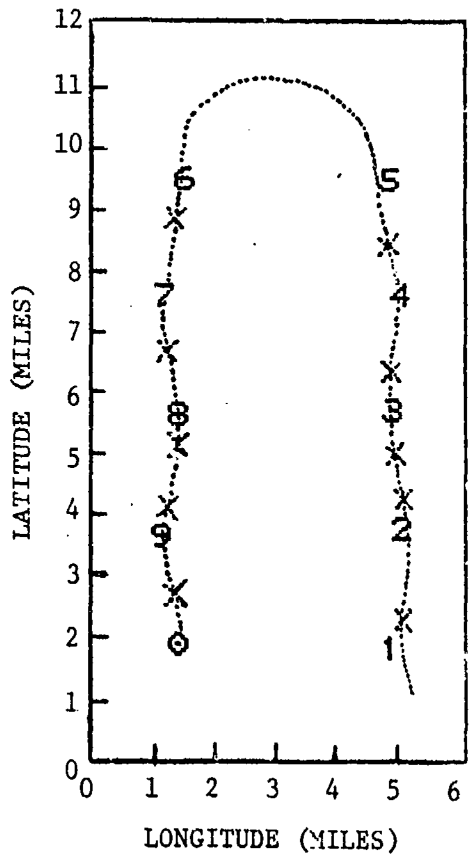
<u>Time constraints</u>. A minimum of ten seconds was required to lapse between trials. This minimal period was needed to allow the subject to recover from the effects of the previous trial and therefore avoid possible visual-motion conflicts which could result in the confounding of data. The status display provided a digital clock that showed time, in seconds since the onset of the last trial.

<u>Heading and attitude constraints</u>. In addition to level attitude, the heading was required to be towards the next target. The television monitor and the system status display were used to determine the attitude and heading requirements.

Control stick input constraints. The subject's control stick activity was required to be within minimum limits and to be stable. The required limits were established from data collected in the preliminary investigation (see Performance Measures). A CRT display provided the experimenter with the extent of raw stick deflection being input by the subject. A calibrated mask was affixed over this display to represent the limits of input in percent stick deflection.

Location and randomization constraints. All trials were presented between the targets and after the subject had completed the necessary heading corrections. To avoid problems of anticipation, the presentation of trials occurred at different locations on the tracking course. Thus, for example, one trial would be presented between targets 1 and 2, two between 2 and 3, one between 3 and 4, one between 4 and 5, etc. On the next block, two trials would be presented between targets 1 and 2, none between 2 and 3, two between 3 and 4, one between 4 and 5, etc. A count of the number of trials already presented was shown on the status display. The location of trials was shown on the ground track display. An example of this display is illustrated in Figure 13. The numbers on this display represented the location of the ten targets on the terrain model. The Xs showed the location of the trials over the subject's tracking course (dotted line). Upon the presentation of a stimulus, the display was updated with an X. Also updated was the tracking course to show the progress of the subject.

When all the criteria were met, the experimenter pressed the insert button, which caused an output to be made for the preselected trial. A 45 sec. rest period was provided between blocks of trials. For the purpose of safety, the subject was assisted in exiting the control station after the completion of each session. The last session was followed with a debriefing, a tour of the simulation facility, and a discussion on the purposes of the experiment.



Location of Targets

Target	Latitude (Miles)	Longitude (Miles)
1	1.21	4.91
2	3.24	5.11
3	5.30	4.88
4	7.28	5.07
5	9.29	4.89
6	9.32	1.81
7	7.23	1.50
8	5.24	1.67
9	3.14	1.37
10	1.28	1.69

Figure 13. Ground track display and location of targets. The numbers on the display represented the location of the ten targets on the terrain model. The Xs show the location of trials over the tracking course (dotted line).

Performance Measures

Data Acquisition

Data collected during all sessions (including training) were recorded on 9-track magnetic tape. Data acquisition was initiated at the moment that the system was released to the subject and was discontinued when tracking had reached the last target. The variables, units, and sampling rate on each are discussed below.

Time. Clock time into the tracking task was recorded every .05 sec.

Lateral control stick deflection (roll axis). The lateral control stick activity was recorded in percent deflection from the center position (i.e., 0 percent) to full deflection (i.e., 100 percent). The direction of deflection (+ for right stick and - for left stick) was recorded simultaneously with percent deflection. Data were acquired at a rate of 20 samples/sec. (i.e., every .05 sec.).

Longitudinal control stick deflection (pitch axis). The longitudinal control stick activity was recorded in percent deflection from the center position (i.e., 0 percent) to full deflection (i.e., 100 percent). The direction of deflection (+ for aft stick and - for fore stick) was recorded simultaneously with percent deflection. Data were acquired at a rate of 20 samples/sec. (i.e., every .05 sec.).

Longitude. Longitude was the location of the simulated remotely piloted vehicle over the terrain model in an east-west direction. Data were acquired at a rate of 10 samples/sec. (i.e., every .1 sec.) and were converted to feet traveled from the left (i.e., west) side of the terrain model.

Latitude. Latitude was the location of the simulated vehicle in a direction running lengthwise over the terrain model (i.e., south-north). Data were acquired at a rate of 10 samples/sec. (i.e., every .1 sec.) and were converted to feet from the lower end of the terrain model.

Altitude. Altitude was measured in feet above sea level. Data were acquired at a rate of 10 samples/sec. (i.e., every .1 sec.).

Header information. Two kinds of header information were recorded. The first was inserted prior to the initiation of each tracking task. Included was the subject identification number, experimental condition, and block number. The second type was inserted at the time of each trial. Included was the trial number and the visual and/or motion combination used.

Tolerance Limits on Control Stick Activity

As noted earlier, the tracking task was analogous to contact flying. Since a subjective compensatory component was present in the task, it was expected that the subject would tend to make small, but frequent corrections. Thus, it was necessary to seek bands of allowable tolerance for the task (i.e., the small control stick deflections to be regarded as noise rather than responses to trials). The primary purpose of this exercise was to (1) select tolerance limit values to be used as decision criteria (see Procedures) for presenting the subject with trial stimuli, and (2) to identify the temporal location in the tracking record in which the subject responded to the stimulus (i.e., the point in the tracking record where stick deflection first exceeded the tolerance limit).

The method used to obtain tolerance limits is described in Appendix H. Briefly, it consisted of a frequency count of lateral and longitudinal stick activity at various levels of deflection. Since stick deflections were sampled every .05 sec., it was possible to compute the percent of time that subjects maintained the stick at or within various preselected levels. The results of this exercise

revealed that the average lateral stick activity was at or below ±20 percent deflection 75 percent of the time. Similarly, longitudinal stick activity was at or below ±7 percent 75 percent of the time. These two values were used as decision criteria for presenting stimuli and for computing the performance measures. The values used in the former process were obtained from the preliminary investigation described in Appendix A.

Computed Performance Measures

Computer programs were developed to retrieve data from magnetic tape and to compute relevant performance measures. These measures were: target tracking error; initial response time (RT) and movement rate (MR); correction RT and MR to errors; amendment time; and proportion of errors. These measures are discussed below:

Target tracking error. Target tracking error was a rough estimate of the subject's capability to perform the target tracking task. This estimate was not regarded as analogous to time on target (TOT) measures because of the subjective nature of the task. A computer program determined the longitude of the simulated vehicle when it reached a latitudinal position 18 ft. (5.5 m) from the target. The target tracking error was the difference between the vehicle longitude and the target longitude in feet.

Initial responses. The initial response refers to the first response occurring after the onset of a stimulus. Four types of responses were possible: (1) correct; (2) reversal error; (3) axis error; and (4) cross-coupled. Response time was defined as the time

interval between the onset of a stimulus and the first point (i.e., sample) in the tracking record of either axis (i.e., lateral and longitudinal) in which control stick deflection exceeded the tolerance limit.

Since a response was defined in terms of criterion values, there was a certain amount of unavoidable data loss. This loss of data was due to two factors. First, if the control stick deflection did not exceed the tolerance limit value within a period of two seconds following the onset of a stimulus, it was inferred that the subject had not responded to the stimulus. Second, if control stick deflection was above the criterion value at the onset of a stimulus, the subject's response was disregarded and was identified as experimenter error. With the exception of the MO condition, the total data loss represented eight percent of the total trials (see Appendix F). Only experimenter error was considered in the MO condition because a response to motion was itself an error response. Experimenter error in this condition was eight percent.

An illustration of a tracking record resulting from a typical correct response to a pitch down stimulus is presented in Figure 14. Also shown in this figure is the interval in which response time was computed. The dashed line represents the tolerance limit value for longitudinal stick deflection. The abscissa is the reference axis to the time elapsed from the beginning of an experimental block of trials. In this illustration, 104 sec. was the point where a trial was presented to the subject. Note that stick deflection crossed the tolerance limit (+7 percent stick deflection) .50 sec. after the onset of the stimulus.

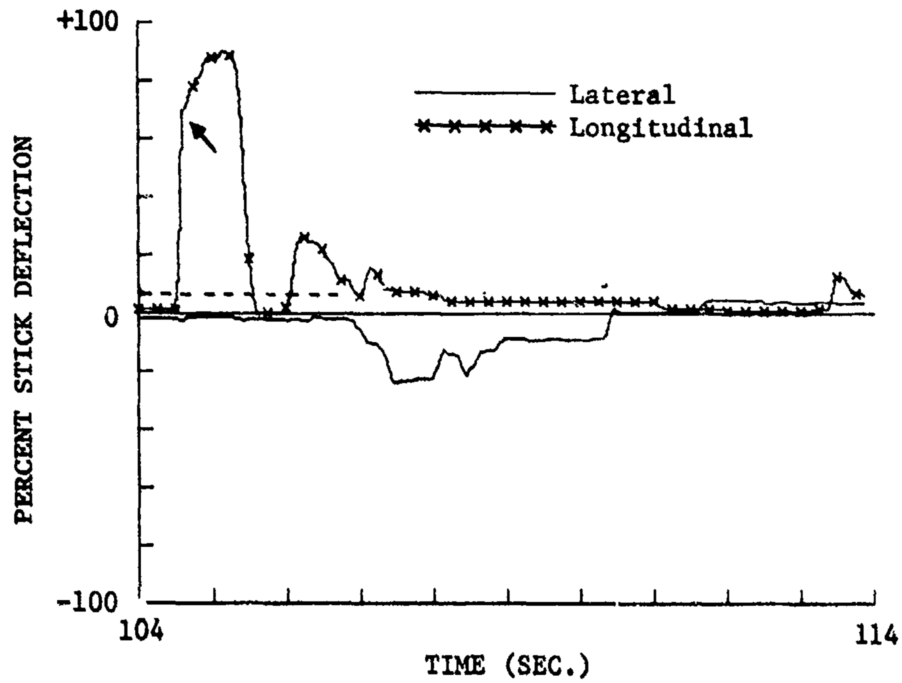


Figure 14. Tracking record of a typical correct response to a pitch down stimulus. The abscissa is the time elapsed from the start of an experimental block. The onset of the stimulus occurred 104 sec. into the task and the response time was the interval between the onset and the point where stick deflection was at, or first crossed the tolerance limit (the dashed line). The arrow points to the location in which maximum stick deflection was determined (see text, p. 77).

The subject made his correction with an aft stick deflection to null the error produced by the stimulus. Figure 15 illustrates reversal errors to stimuli in the SAI condition. The stimulus represented in Figure 15a was a visual roll to the left and a roll motion to the right. A correct response required that the subject deflect the control stick to the right in order to null the effects of the error. Note, however, that the subject's initial response was with a stick deflection to the left,

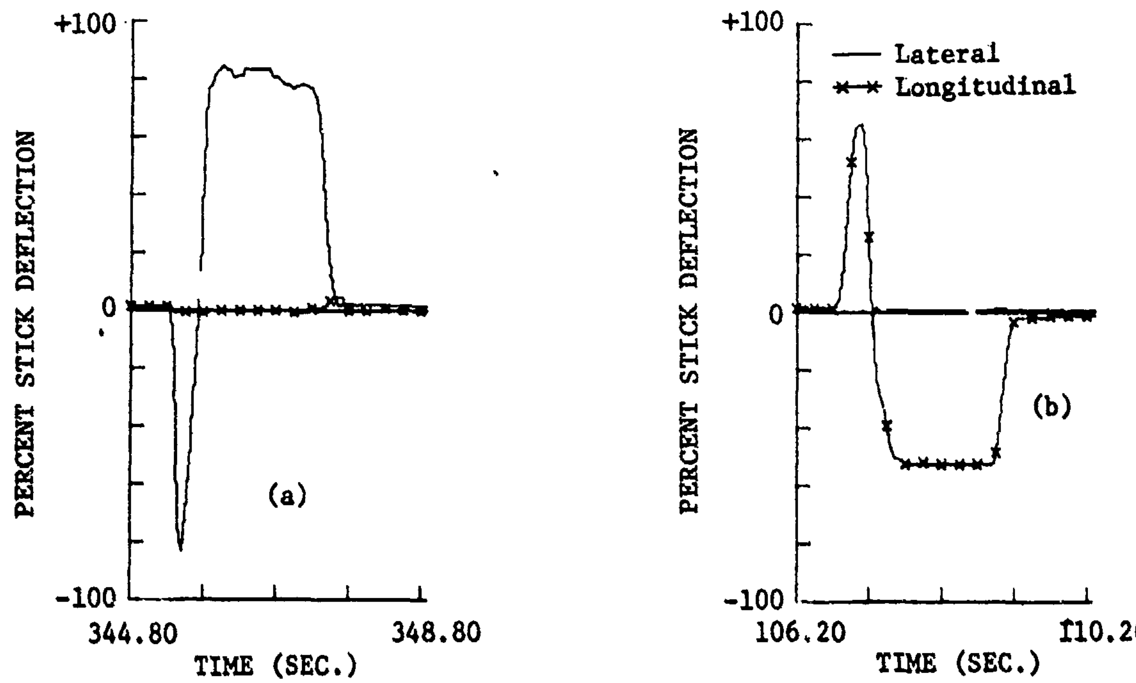


Figure 15. Tracking records of typical reversal errors to trials in the SAI condition. The stimulus combination in Figure 15a was a visual roll to the left and a roll motion to the right. The subject's initial response was with a stick deflection to the left, which resulted in a reversal error. The stimulus combination in Figure 15b was a visual pitch up and a pitch down of the motion. The subject's initial response was with an aft stick deflection, which resulted in a reversal error.

which added error to the already existing stimulus error. The large deflection from about -84 percent to about +82 percent was to null the effects of the reversal error plus the error due to the stimulus. Figure 15b is another illustration of a reversal error, but the stimulus relationship was on the pitch axis (visual pitch up and pitch down on the motion). Figure 16 illustrates initial responses on the wrong axis (i.e., axis errors) resulting from trials in the DAI condition. The

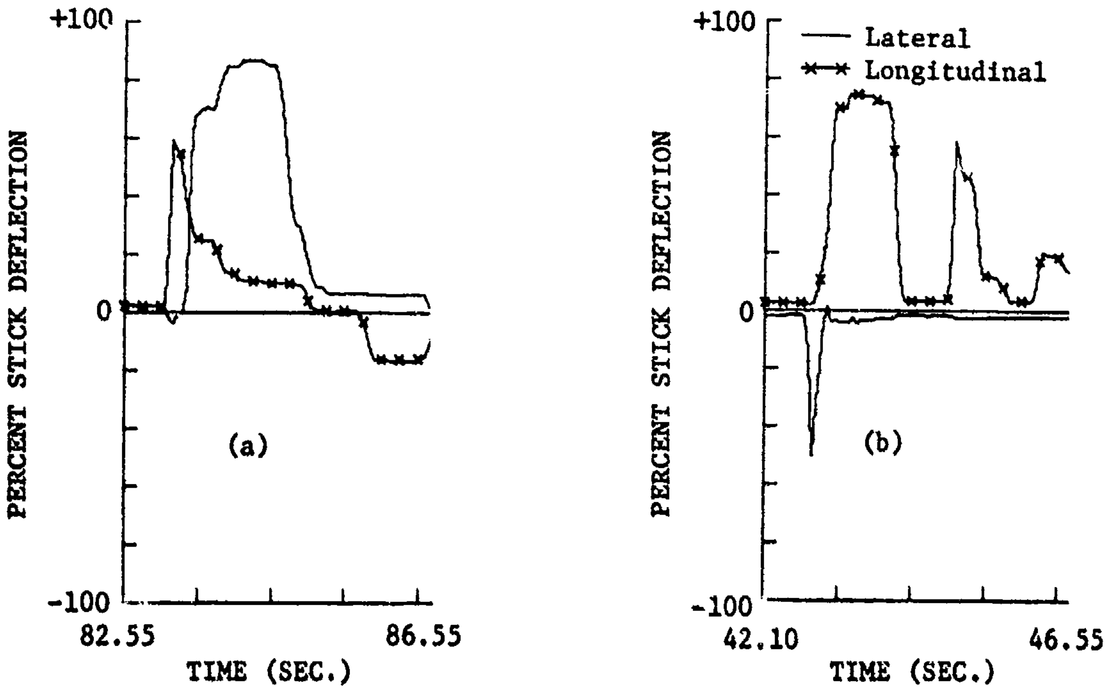


Figure 16. Tracking records of typical axis errors to trials in the DAI condition. The stimulus combination in Figure 16a was a visual roll to the left and a pitch down of the motion. The initial response was with an aft stick deflection, which resulted in an axis error. The stimulus combination in Figure 16b was a visual pitch down and a roll motion to the right. The initial response was with a stick deflection to the left, which resulted in an axis error.

stimulus combination represented in Figure 16a was a visual roll to the left and a pitch down of the motion. The initial response was with a longitudinal stick deflection and was in the correct direction had the subject been required to respond to the motion stimulus (i.e., an aft deflection in response to the pitch down of the motion). The subject's stick deflection added error, but on a different axis to that produced by the visual stimulus (i.e., roll). Similarly, Figure 16b illustrates

a response to a visual pitch down and a roll motion to the right. Again, the subject responded first to the motion stimulus.[3] In contrast to the DAI condition, axis errors in VO, SAI, and SAC could not be attributed directly to motion cues (in VO there was no motion and in SAI and SAC, motion was on the same axis as the visual stimulus). Finally, a cross-coupled response to a trial refers to lateral and longitudinal stick deflections, which occur simultaneously. Figure 17 illustrates this type of response. Four percent of the trials in VO, SAI, SAC, and DAI resulted

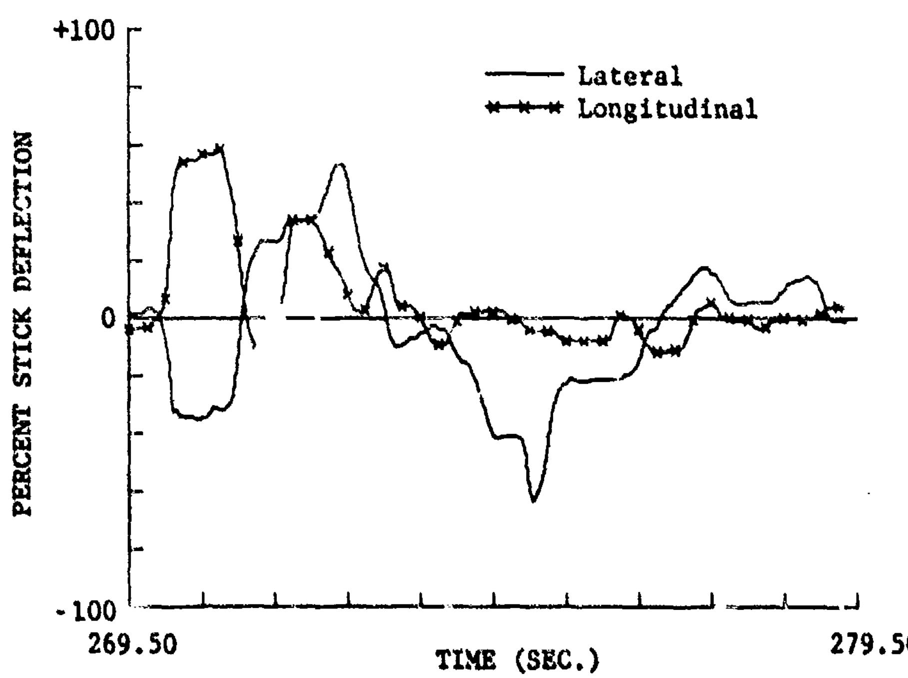


Figure 17. Tracking record of a typical cross-coupled response to a trial in the DAI condition. The stimulus combination was a visual pitch down and roll motion to the right. The subject responded to both the visual and motion cues simultaneously.

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[3]Two percent of the axis errors in the DAI condition were in the wrong direction with respect to motion. These data were not included in the analysis (see Appendix F).

in cross-coupled responses. These data were not submitted to analysis because of their random occurrence (except for large differences in the number of these responses between pitch and roll) and because they provided little or no substantiation of the issues being investigated (i.e., these data could be regarded as neither correct nor error responses).

In addition to response time, the movement rate of control stick deflection was determined on all initial responses. Rate was computed in °/.05 sec. of stick deflection from the initiation of a response to the point where stick position reached maximum deflection. Movement rate was computed in accordance with the equation:

$$MR = \frac{.25(A-B)}{T}$$

where

A = percent maximum amplitude of stick deflection. Maximum amplitude was defined as that point where the difference in stick deflection on two consecutive .05 sec. samples was less than .005 percent units, or the point where deflection changed direction. The arrow shown in Figure 14 points to the position in the tracking record where maximum stick deflection was computed in accordance with this definition.

B = percent stick deflection at the point where it first exceeded the tolerance limit. (This point was used also to determine response time.)

.25 = scale factor for converting percent to degrees (25° represented 100 percent, or full, stick deflection).

T = number of time samples between A and B.

Correction responses. Correction RTs and correction MRs were computed on all reversal and axis errors. Correction RT to a reversal was the time interval between the onset of a stimulus and the initiation of a correction. The latter was determined by finding the start point where stick deflection was initiated in the correct direction. This point was located in the tracking record by applying a technique similar to the one used to determine maximum amplitude of stick deflection. This method was employed because a correction response did not always occur immediately after reaching the computed maximum amplitude of the initial response. Hesitations, or small stick deflections, would be occasionally input by the subject prior to the initiation of a correction. The point where a correction response was initiated was located by scanning the tracking record in both forward and backward directions. The terminal point of the corrective movement was located by scanning forward and finding the point where deflection first entered the tolerance limit. By scanning backwards from this point it was possible to find maximum amplitude of stick deflection which occurred just prior to the corrective movement. The time interval between the onset of the stimulus and the point on the time record where the computed maximum amplitude was reached was defined as correction RT. The percent stick deflection at this maximum amplitude and at the terminal point of the correction were used to compute correction MRs as described earlier.

Correction RTs to axis errors were determined by searching for the point where stick deflection in the correct axis first exceeded the tolerance limit. Both correction RTs and MRs were then computed by applying the technique used on correct responses.

<u>Amendment time</u>. A post hoc analysis of data was conducted to determine the amendment time (or error detection time) to reversal errors. This measure was the averaged difference between initial RT to reversals and the correction RT. Computation of amendment time was limited to SAI data because of the relatively large number of reversals made in that condition by all subjects. Analysis of these data was stimulated by previous investigations conducted on sensory feedback by Chernikoff and Taylor (1952), Gibbs (1965), and Higgins and Angel (1970).

<u>Error rates</u>. The proportion of reversal and axis errors was computed from data on all experimental conditions, except MO. The primary purpose of this measure was to determine: (1) possible effects due to practice; and (2) possible differential effects by types of errors (reversals vs. axis errors), due to conditions and experience. All proportions were obtained by dividing the number of errors by the total number of responses. Since all responses to MO were regarded as errors in this experiment, proportions were obtained by dividing the number of responses by the total number of trials (experimenter errors were excluded).

RESULTS

The experimental findings are arranged in accordance with the list of dependent variables discussed in the Experimental Procedure, namely, response time (RT), movement rate (MR), amendment time, and error rate. While the experimental findings are presented in context with the major issues explored, detailed interpretation and conclusions drawn from the data are reserved for the Discussion.

The first major topic to be covered deals with RT and MR data. Results obtained in the visual only (VO), single axis incompatible (SAI), and single axis compatible (SAC) conditions are presented first. Analysis proceeded in accordance with the events shown in Figure 18.

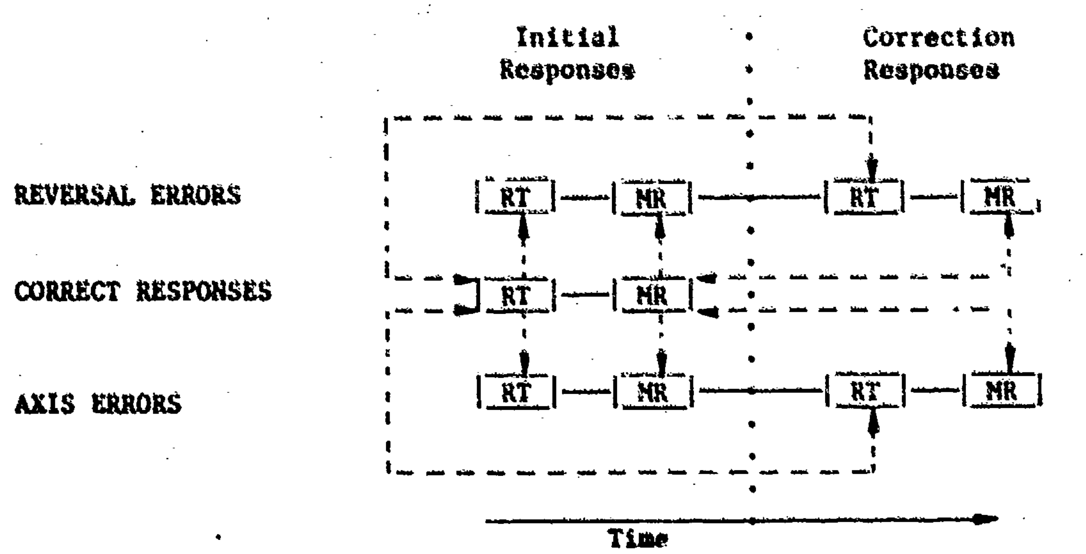

Figure 18. Sequence of events and statistical comparisons. The solid lines represent response sequences and the dashed lines represent data comparisons.

Response times and MRs on initial responses (i.e., correct responses, reversal errors, and axis errors) were submitted to analysis of variance to determine possible effects due to practice, conditions, experience, and the axis in which the visual stimulus occurred. Similarly, correction RTs and MRs on reversal and axis errors were analyzed to determine whether the response characteristics exhibited the same, or similar, patterns to those on the initial responses. Finally, correction RTs and MRs were compared to RTs and MRs on the initial responses.

Next discussed are the RTs and MRs obtained in the motion only (MO) condition. These data were not compared statistically with the other three conditions because of the different nature of the task. Since no visual stimuli were presented to the subjects in this condition, the responses were few and those that were made were regarded as errors. Nevertheless, the data were analyzed for possible effects due to experience and axis. Corrections to these error responses were not examined.

The results obtained from the double axis incompatible (DAI) condition are then examined. As will be recalled, this condition was administered to pilots only. Two sets of analyses were carried out on the data. The first tested for possible effects due to practice and the second compared DAI with VO, SAI, and SAC on pilots. The discussion of the results proceeds in a fashion similar to the one illustrated in Figure 18, except that the data were not compared across experience groups.

The second major topic covers the amendment time data. As indicated in the Experimental Procedure, the analysis was limited to RT data in

SAI where a greater proprotion of reversal errors were made. The effects due to experience and practice are examined.

The third and final topic, examines the error rate data. This discussion is organized as in the first topic. The results obtained in VO, SAI, and SAC are presented first, and this is followed with a discussion of the results obtained in MO and DAI.

A summary of the total number of trials presented to the subjects in each condition and experience group, by axis, is presented in Appendix F. This summary includes a tabulation of the total number of responses, by type of response (i.e., correct, reversal error, axis error, and cross-coupled), on each axis. Also included is the total number of responses lost because of experimenter error and/or because the subject failed to respond to a stimulus. Accordingly, the total number of observations submitted to analysis was determined by subtracting the total data lost from the total number of trials. (The number of observations is presented in the Total Response column in Appendix F.) Finally, all analyses of variance reported were performed with the VUL2 - Vanderbilt Statistical Package (1971). The missing data (i.e., unequal n) option supplied with these programs was applied where needed.

Prior to proceeding with the experimental findings, it might be well to present a brief summary of the results obtained on target tracking error. These data are presented here because they are not directly relevant to the issues explored in this experiment. It will be recalled that this measure was a rough estimate of the subject's capability to perform the tracking task.

Mean tracking error (pooled across conditions) on each experience group over sessions, is presented in Table 2. In contrast to non-pilots, the pilots did not exhibit a large reduction of error over sessions. As expected, the non-rated subjects manifested the greatest amount of learning. By the last session, all experience groups were approximately equal in their ability to perform the tracking task. While there was some difference among groups in the first session, it was concluded that all subjects were fully capable of performing the required task.

TABLE 2

Mean Target Tracking Error (in ft.)

Sessions	Pilots	Navigators	Non-rated
1	161.9	226.4	343.9
2	160.1	222.2	249.9
3	156.8	177.1	206.9
4	166.1	184.4	187.2

Upon further examination of Table 2, it would appear that the errors are rather large; in fact they are extremely small. There are two related reasons for making this assertion. First, while subjects felt that they had actually flown the simulated remotely piloted vehicle over a target at the point where the target left the field of view at the bottom of the screen, the vehicle was still 725 ft. (220.99 m) away from the target. This was because the vehicle simulated had a forward looking visual system that subtended a vertical angle of 38° over the terrain model. Target tracking error was determined from a latitudinal distance of 18 ft. (5.5 m) from the target. At this point, however, the

subject had already initiated his corrections to the next target and the distance of the vehicle was determined to be, on the average, 81.4 ft. (24.8 m) longitudinally away from the target. Accordingly, the latter figure must be considered to be a constant error, which is included in the figures presented in Table 2. Second, the scene shown on the television monitor represented a viewing angle that subtended 50° horizontally over the terrain model. At an altitude of 500 ft. (152.4 m), the horizontal field of view at the location of the upcoming target represented approximately 1.87 statute miles (3.01 km) and the angle subtended by the target at two miles (the distance between targets) was only 40' of a degree. Considering the apparent size of the target at this distance, as well as the miles flown, the errors presented in Table 2 are very small.

Response Time and Movement Rate

Visual Only (VO) versus Single Axis Incompatible (SAI) versus Single Axis Compatible (SAC)

Correct responses. Analyses of variance were performed on the RTs for each experience group (within conditions) to determine possible effects due to practice and directionality of response in each axis (i.e., pitch up vs. down and roll right vs. left). Neither of these variables was found to be significant; therefore, RTs were pooled over sessions and over directionality. Mean RTs on correct responses are shown in Table 3. There was a significant effect due to conditions, F (2, 27) = 6.34, p < .01, (.75, .66, and .57 sec. in VO, SAI, and SAC, respectively) and to experience, F (2, 27) = 5.57, p < .01 (.56, .72,

TABLE 3

Mean Response Times (in sec.) on Correct Responses

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	.58	.66	.67	.71	.96	.89
SAI	.51	.71	.61	.58	.84	.74
SAC	.48	.52	.57	.54	.61	.68

and .70 sec. on pilots, navigators, and non-rated, respectively). Also significant was axis, F (1, 27) = 71.90, $p < .01$, with mean RT being shorter to pitch than roll (.59 vs. .73 sec.). A Conditions X Axis interaction, F (2, 27) = 6.32, $p < .01$, revealed that the effect due to the absence of motion in the VO condition was primarily in the roll axis and not pitch.

To arrive at a better understanding of the significant effects due to conditions, experience, and the Conditions X Axis interaction, analyses of variance were carried out on the RTs on each axis. Conditions was significant on pitch, F (2, 27) = 3.77, $p < .05$ and roll; F (2, 27) = 7.51, $p < .01$. A Newman-Keuls (Winer, 1971, p. 191) test of the means on the pitch axis revealed that RT in VO was significantly longer than SAC ($p < .05$), but not SAI. On the roll axis, RT in VO was significantly longer than both SAI and SAC ($p < .01$). Taken together, these two tests provide some insight into the Conditions X Axis interaction, namely, that the absence of motion had its primary effect in roll, rather than pitch. While mean RTs in SAI and SAC did not differ significantly on either axis, there was a tendency for SAC to result in shorter RTs than SAI on both axes (.52 vs. .61 sec. on

pitch and .61 vs. .72 sec. on roll). Thus, compatible visual-motion relationships tended to provide cues which aided performance. The failure to obtain a significant difference between SAI and SAC, however, suggests that motion, even when it is incompatible with the visual stimulus, aids performance by reducing response time.

Finally, experience was significant on both pitch, $\underline{F}$ (2, 27) = 4.01, $\underline{p}$ < .05 and roll, $\underline{F}$ (2, 27) = 5.70, $\underline{p}$ < .01. Newman-Keuls tests of the mean RTs on all experience groups revealed that pilot RT was significantly shorter than that of non-pilots ($\underline{p}$ < .05 on both pitch and roll), but the two non-pilot groups did not differ ($\underline{p}$ > .05).

As with RTs analyses of variance were carried out on MRs for each experience group (within conditions) to determine possible effects due to practice and directionality. Neither of these variables was significant; therefore, MRs were pooled over sessions and over directionality in each axis. The mean MRs are summarized in Table 4. Neither conditions, $\underline{F}$ (2, 27) = 3.26, $\underline{p}$ > .05 (4.0, 4.4, and 3.2°/.05 sec. in VO, SAI, and SAC, respectively) nor experience, $\underline{F}$ (2, 27) = .19, $\underline{p}$ > .05 (4.0, 3.9, and 3.7°/.05 sec. on pilots, navigators, and non-rated, respectively) was significant. Axis was significant, $\underline{F}$ (1, 27) = 137.12, $\underline{p}$ < .01, with pitch resulting in slower MRs than roll (2.8 vs. 5°/.05 sec.). There was a significant Conditions X Axis interaction, $\underline{F}$ (2, 27) = 7.34, $\underline{p}$ < .01.

To gain a better understanding of the nature of the Conditions X Axis interaction, analyses of variance were performed on data from each axis separately. Conditions failed to reach significance on pitch,

TABLE 4

Mean Movement Rates (in °/.05 sec.) on Correct Responses

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	3.1	2.3	2.9	5.1	5.7	5.1
SAI	3.3	2.7	2.9	5.8	5.9	6.0
SAC	3.0	2.6	2.2	3.0	4.4	3.3

F (2, 27) = 1.04, $p > .05$, but was significant on roll, F (2, 27) = 13.8, $p < .01$. A Newman-Keuls revealed that MR in SAC was significantly slower ($p < .05$) than in SAI and VO on the roll axis. Thus, the effect of compatible visual-motion relationships was to reduce the rate of movement, but this was apparent on the roll axis only. Unlike RT, however, this effect was limited to the compatible relationship (i.e., there was no difference in MR on the roll axis between VO and SAI).

In summary, the effects of practice, conditions, experience, and axis on correct responses to stimuli, as revealed by RT and MR measures, may be characterized as follows: (1) Practice did not have an effect on RTs and MRs. (2) The absence of motion lengthened RT, but this effect was primarily on the roll axis. While there was no difference in RT between the two motion conditions (SAI and SAC), there was a tendency for compatible relationships (SAC) to result in shorter RTs to both pitch and roll. A strict interpretation of these results, however, would suggest that an incompatible relationship has no effect on RT of correct responses. The results may be also interpreted to mean that motion, even though in conflict with the visual stimulus, provides cues

(information) which aid performance by shortening RT to stimuli on the roll axis. The MRs did not differ among conditions on the pitch axis. Compatible visual-motion relationships resulted in slower MRs on the roll axis. There was a slight tendency, though not statistically significant, for SAI to result in faster MRs on both axes. (3) Experience had a significant effect on RT. Pilots responded with shorter RTs than non-pilots on both axes. Experience had no effect on MRs. (4) Mean RT was shorter and mean MR was slower to pitch than roll.

Reversal errors. Analyses of variance were performed on the RTs and MRs for each experience group (within conditions) to determine any possible influence due to practice and directionality. Neither of these variables was significant; therefore, RTs were pooled over sessions and over directionality in each axis. Mean RTs on reversal errors are presented in Table 5. Unlike correct responses, RTs on reversals did not differ among conditions, F (2, 27) = 3.29, p = .052 (.47, .42, and .34 sec. in VO, SAI, and SAC, respectively), or experience groups,

TABLE 5

Mean Response Times (in sec.) on Reversal Errors

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	.38	.35	.36	.48	.57	.65
SAI	.37	.45	.32	.43	.49	.49
SAC	.22	.24	.37	.35	.39	.47

$\underline{F}$ (2, 27) = 1.02, $\underline{p} > .05$ (.37, .42, and .44 sec. on pilots, navigators, and non-rated, respectively). It should be noted, however, that there was a tendency (see Table 5) for VO to result in longer RTs and for pilots to respond with shorter RTs than non-pilots. Like correct responses, RTs on reversals to pitch were shorter than to roll, $\underline{F}$ (1, 26) = 16.91, $\underline{p} < .01$ (.34 vs. .48 sec.). Similarly, MRs associated with reversal errors, as shown in Table 6, did not differ among conditions, $\underline{F}$ (2, 27) = 1.30, $\underline{p} > .05$, (2.4, 2.7, and 1.6°/.05 sec. in VO, SAI, and SAC, respectively) or among experience groups, $\underline{F}$ (2, 27) = .62, $\underline{p} > .05$ (2.2, 2.1, and 2.5°/.05 sec. on pilots, navigators, and non-rated, respectively). Finally, MRs to pitch were significantly slower than roll, $\underline{F}$ (1, 26) = 46.52, $\underline{p} < .01$ (.9 vs. 3.6°/.05 sec.), as found on MRs on correct responses.

TABLE 6

Mean Movement Rates (in °/.05 sec.) on Reversal Errors

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	1.5	.2	.8	3.1	3.9	5.4
SAI	1.3	1.4	1.0	5.1	3.5	4.2
SAC	.5	.6	.9	1.9	2.7	2.7

A comparison was made of mean RTs and MRs on reversals with mean RTs and MRs on correct responses, by axis. Response times on reversals were significantly shorter than correct responses on pitch (.35 vs. .59 sec.), $\underline{F}$ (1, 26) = 98.07, $\underline{p} < .01$ and roll (.48 vs. .73 sec.),

F (1, 26) = 51.29, $p < .01$. Similarly, MRs on reversals were significantly slower than correct responses on pitch (.9 vs. 2.8°/.05 sec.), F (1, 26) = 123.4, $p < .01$ and roll (3.6 vs. 5.0°/.05 sec.), F (1, 27) = 13.7, $p < .01$. There were no significant interactions.

Correction RTs to reversals are summarized in Table 7. In contrast to correct responses, correction RTs failed to show an effect due to conditions, F (2, 27) = 2.03, $p > .05$. There was, however, a slight tendency for RTs in VO to be longer than in SAI and SAC (.66, .59, and .53 sec.). Experience was significant, F (2, 27) = 5.5, $p = .01$, with pilots showing shorter RTs, followed by navigators and non-rated subjects (.49, .60, and .70 sec.). A Newman-Keuls test revealed that the difference was between pilots and non-pilots ($p < .05$) as was the case with RTs on correct responses. Mean correction RT to pitch was shorter than to roll (.53 vs. .66 sec.), F (1, 26) = 8.08, $p < .01$. There were no significant interactions.

TABLE 7

Mean Correction Response Times (in sec.) to Reversal Errors

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	.51	.50	.51	.61	.77	1.10
SAI	.48	.73	.49	.49	.66	.70
SAC	.36	.42	.73	.46	.52	.71

Correction MRs to reversals are presented in Table 8. There was a significant effect due to conditions, F (2, 27) = 3.54, p < .05 (2.8, 4.0, and 2.7°/.05 sec. in VO, SAI, and SAC, respectively). A Newman-Keuls test revealed that SAI resulted in significantly faster MRs than VO and SAC (p < .05). It will be recalled that the MRs on correct responses did not result in a conditions effect, although there was a tendency for SAI to result in slightly faster MRs. As with correct responses, experience was not significant, F (2, 27) = .55, p > .05 (3.4, 3.0, and 2.7°/.05 sec. on pilots, navigators, and non-rated, respectively), but axis was, F (1, 26) = 57.11, p < .01, with pitch resulting in slower MRs than roll (2.3 vs. 4.0°/.05 sec.).

TABLE 8

Mean Correction Movement Rates (in °/.05 sec.) to Reversal Errors

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	2.3	1.7	2.7	3.5	3.1	3.7
SAI	3.5	2.9	2.6	5.8	4.3	4.7
SAC	2.5	1.3	1.7	3.3	3.9	3.5

The relationship existing between RTs and MRs on reversal errors and the RTs and MRs required to correct these errors in each condition, is presented in Figure 19. Also shown in the figure are the RTs and MRs on correct responses. A comparison was made of mean RTs and MRs on corrections to reversals with the mean RTs and MRs on correct responses, by axis, to determine whether correction RTs and MRs approached those of correct responses. The mean time required to detect and correct an

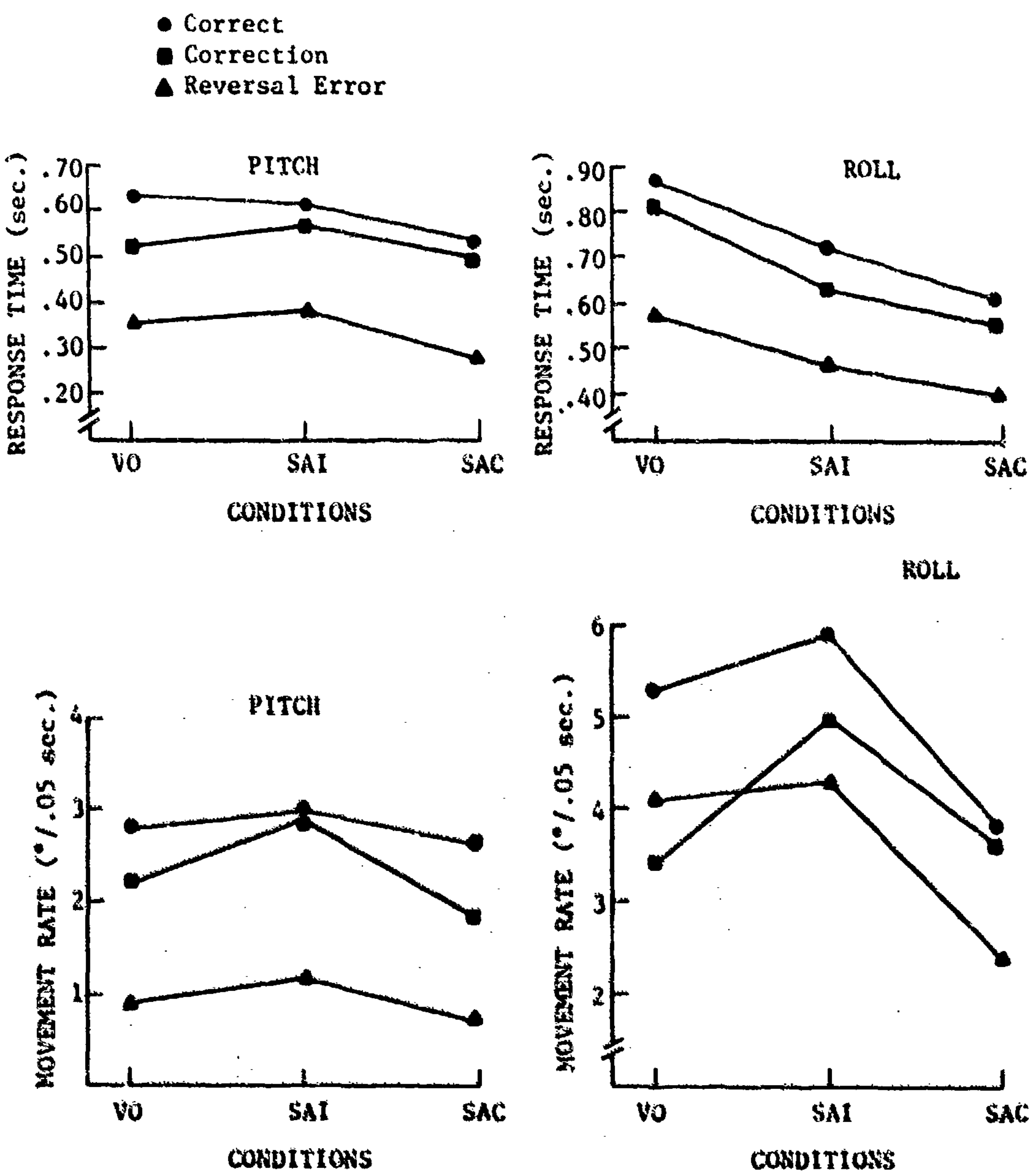

Figure 19. Response time and movement rate on correct responses, reversal errors, and correction to errors as a function of conditions.

error (i.e., correction time) approached that of correct responses as revealed by the absence of significant effects on pitch, F (1, 26) = 2.48, $p > .05$ (.53 vs. .59 sec. on correction and correct, respectively) and roll, F (1, 27) = 2.97, $p > .05$ (.67 vs. .73 sec. on correction and correct, respectively). There were no significant interactions with conditions and experience on either axis. Unlike correction RTs, correction MRs to pitch were significantly slower than MRs on correct responses, F (1, 26) = 11.37, $p < .01$, even though the difference appeared to be very small (2.3 vs. 2.8°/.05 sec. on correction and correct, respectively). Similarly, correction MRs to roll axis stimuli were slower than MRs on correct responses, F (1, 27) = 17.87, $p < .01$ (4.0 vs. 5.0°/.05 sec. on correction and correct, respectively). There was a significant Conditions X Response (i.e., correction and correct) interaction on both pitch, F (2, 26) = 3.63, $p < .05$ and roll, F (2, 27) = 3.57, $p < .05$. The interaction on the pitch axis was due to the relatively large differences between correction and correct MRs in VO and SAC. In the SAI condition, however, correction MR approached that of correct responses (3.0 vs. 2.9°/.05 sec.). On the roll axis, correction MR in SAC approached that of correct responses (3.6 vs. 3.8°/.05 sec.), but VO and SAI did not.

In summary, the effects due to practice, conditions, experience, and axis on reversal errors and corrections to these errors, as revealed by RT and MR measures, may be characterized as follows: (1) Practice did not have an effect on RTs and MRs of reversal errors. (2) In contrast to correct responses, there were no differences in mean RTs and MRs among conditions on either axis. There was a tendency for VO

to result in longer RTs and for SAI to result in faster MRs (as with correct responses), but neither was statistically significant. (3) In contrast to correct responses, there were no differences in the RTs and MRs among experience groups. There was a tendency for pilots to respond with shorter RTs than non-pilots, but the difference was not significant. (4) As with correct responses, RTs on reversals were shorter to pitch than roll, and MRs were slower to pitch than roll. (5) Mean RTs on reversals were shorter than on correct responses and MRs were slower, on both axes. (6) Correction RTs to reversals did not show an effect due to conditions. (There was a tendency for VO to result in shorter RTs, as was found on correct responses.) In contrast to RTs on reversals, correction RTs revealed a significant effect due to experience, with pilots having shorter RTs than non-pilots. Correction RTs to pitch were shorter than to roll. In contrast to RTs, conditions had a significant effect on MRs, with MR being faster in SAI than VO and SAC. (This finding is similar to that of MRs on correct responses and reversal errors, although the latter were not statistically significant.) Experience had no effect on MRs. Finally, correction MRs were slower to pitch than roll. (7) Correction RTs approached those of correct responses. While there was a consistent trend for correction RTs to be somewhat shorter than RTs on correct responses, these were not statistically significant on either axis. In contrast to RTs, there was a significant difference between correction MRs and MRs on correct responses. This difference was attributed to VO and SAC on the pitch axis and to VO and SAI on the roll axis.

<u>Axis errors</u>. Because of the few and scattered number of axis errors, RTs were pooled over sessions and over directionality in each axis. Mean RTs on axis errors are shown in Table 9. Unlike reversal errors, there was a significant effect due to conditions $\underline{F}$ (2, 27) = 3.81, $\underline{p}$ < .05 (.42, .35, and .33 sec. in VO, SAI, and SAC, respectively). A Newman-Keuls test of the means revealed that mean RT in VO was longer on both pitch ($\underline{p}$ < .05) and roll ($\underline{p}$ < .05), than SAI and SAC (.35, .28, and .28 sec. on pitch and .51, .41, and .38 sec. on roll). Like reversal errors, there was no effect due to experience, $\underline{F}$ (2, 27) = .52, $\underline{p}$ > .05 (.35, .38, and .38 sec. on pilots, navigators, and non-rated, respectively).

TABLE 9

Mean Response Times (in sec.) on Axis Errors

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	.30	.33	.42	.47	.62	.44
SAI	.26	.32	.28	.38	.40	.45
SAC	.28	.24	.34	.42	.38	.36

Axis was significant, $\underline{F}$ (1, 25) = 21.48, $\underline{p}$ < .01, with pitch resulting in shorter RTs than roll (.31 vs. .43 sec.). Similarly, MRs on axis errors, as shown in Table 10, differed among conditions, $\underline{F}$ (2, 27) = 3.69, $\underline{p}$ < .05 (1.8, 1.1, and 1.1°/.05 sec. in VO, SAI, and SAC, respectively), but there was a significant Conditions X Axis interaction, $\underline{F}$ (2, 25) = 5.4, $\underline{p}$ < .05. To gain a better understanding of this interaction, an analysis of variance was carried out on data from

TABLE 10

Mean Movement Rates (in °/.05 sec.) on Axis Errors

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	1.8	2.7	3.7	.8	.9	.6
SAI	1.2	1.0	2.2	.7	.8	1.2
SAC	1.6	2.5	1.0	.4	.9	.7

each axis. Conditions was found to be significant on the pitch axis, $\underline{F}$ (2, 25) = 6.5, $\underline{p}$ < .05, but not on roll $\underline{F}$ (2, 27) = .99, $\underline{p}$ > .05 (2.8, 1.4, and 1.7°/.05 sec. on pitch and .7, .9, and .8°/.05 sec. on roll in VO, SAI, and SAC, respectively). A Newman-Keuls test revealed that VO resulted in faster MRs than SAI and SAC on the pitch axis, but not roll. (Recall that RTs on axis errors were longer in VO than SAI and SAC on both axes.) Like reversals and RTs on axis errors, experience was not significant, $\underline{F}$ (2, 27) = 1.77, $\underline{p}$ > .05 (1.1, 1.4, and 1.5°/.05 sec. on pilots, navigators and non-rated, respectively). While axis was significant, $\underline{F}$ (1, 25) = 37.6, $\underline{p}$ < .01, MRs were faster on pitch than roll (1.9 vs. .7°/.05 sec.), unlike correct responses and reversal errors. It must be recalled, however, that an axis error meant that the control stick deflection to a stimulus in the pitch axis was lateral. The MRs on lateral stick have been found to be typically faster than longitudinal ones.

A comparison was made of RTs and MRs on axis errors with RTs and MRs to correct responses in each axis. As with reversals, RTs on axis errors were shorter than correct responses on both pitch, $\underline{F}$ (1, 25) = 129.2,

$p < .01$ (.30 vs. .59 sec.) and roll, $F(1, 27) = 177.59$, $p < .01$ (.43 vs. .73 sec.). Similarly, MRs on axis errors were significantly slower than correct responses on both pitch, $F(1, 25) = 11.49$, $p < .01$ (1.9 vs. 2.8°/.05 sec.) and roll, $F(1, 27) = 325.92$, $p < .01$ (.7 vs. 5.0°/.05 sec.).

Correction RTs to axis errors are summarized in Table 11. Unlike correction RTs to reversals, where only a trend was noted, there was a significant effect due to conditions, $F(2, 27) = 6.46$, $p < .01$ (.83, .73, and .62 sec. in VO, SAI, and SAC, respectively). An analysis by

TABLE 11

Mean Correction Response Times (in sec.) to Axis Errors

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	.60	.73	.73	.81	1.12	1.01
SAI	.52	.85	.65	.57	.96	.84
SAC	.25	.54	.69	.68	.77	.79

axis revealed a pattern similar to that found on correct responses. Conditions was significant on pitch, $F(2, 25) = 5.38$, $p < .05$ and roll, $F(2, 27) = 4.85$, $p < .05$ (.69, .67, and .50 sec. on pitch and .98, .79, and .75 sec. on roll in VO, SAI, and SAC, respectively). A Newman-Keuls test showed, as with correct responses, that mean RT to pitch in SAC was shorter than in VO and SAI ($p < .05$), but there was no difference between the latter ($p > .05$). Similarly, a Newman-Keuls test on mean RT on the roll axis, revealed that VO resulted in longer RT than SAI and SAC ($p < .05$), but there was no difference between the

latter two ($p > .05$). Experience was significant, F (2, 27) = 10.66, $p < .01$ (.57, .83, and .78 sec. on pilots, navigators, and non-rated, respectively). As with RTs on correct responses and reversal errors, a Newman-Keuls test revealed that the difference was between pilots and non-pilots ($p < .05$). Finally, correction RT to pitch was shorter than to roll (.62 vs. .84 sec.), F (1, 25) = 44.63, $p < .01$. There were no significant interactions with conditions and experience.

Correction MRs to axis errors are presented in Table 12. Unlike correction MRs to reversal errors, there was no effect due to conditions, F (2, 27) = 1.51, $p > .05$ (3.3, 4.0, and 3.1°/.05 sec. in VO, SAI, and SAC, respectively). Like MRs on correct responses, there was a tendency,

TABLE 12

Mean Correction Movement Rates (in °/.05 sec.) to Axis Errors

Conditions	Pitch			Roll		
	Pilots	Navig.	N-R	Pilots	Navig.	N-R
VO	3.2	1.8	2.8	4.4	4.5	2.9
SAI	3.3	2.6	2.6	5.9	4.3	5.2
SAC	3.5	1.7	1.9	3.6	4.7	3.1

though not statistically significant, for SAI to result in faster MRs than VO and SAC. As with correction MRs to reversal errors and MRs on correct responses, experience was not significant, F (2, 27) = 1.6, $p > .05$ (4.0, 3.3, and 3.1°/.05 sec. on pilots, navigators, and non-rated, respectively). Axis was significant, F (1, 24) = 25.01, $p < .01$, with pitch resulting in slower MRs than roll (2.6 vs.

4.3°/.05 sec.), as was found on correct responses and correction MRs to reversal errors. It will be recalled that MRs on axis errors were faster to pitch than roll. Upon correction, however, control stick deflections corresponded with those of the visual stimuli. This finding suggests that the axis effect found on MRs of axis errors was due to differential muscular forces rather than to conflict with the visual stimulus (i.e., lateral stick deflections always result in faster MRs and are independent of the visual stimulus).

The relationship existing between RTs and MRs on axis errors and the RTs and MRs required to correct these errors in each condition is illustrated in Figure 20. Also shown in this figure are the RTs and MRs on correct responses. A comparison was made of RTs and MRs on corrections to axis errors with RTs and MRs on correct responses, by axis. Correction RTs to the pitch axis approached those of correct responses, $\underline{F}$ (1, 25) = 3.09, $\underline{p} > .05$ (.62 vs. .59 sec.). On the roll axis, correction RTs were longer than RTs on correct responses, $\underline{F}$ (1, 27) = 47.29, $\underline{p} < .01$ (.84 vs. .73 sec.). This finding contrasts with correction RTs to reversal errors in which correction RTs did not differ significantly from correct RTs on either axis, but there was a tendency for corrections to be shorter. There were no significant interactions of correct vs. correction RTs with conditions and experience on either axis. Like RTs, correction MRs to pitch approached those of correct responses, $\underline{F}$ (1, 25) = 3.58, $\underline{p} > .05$ (2.6 vs. 2.8°/.05 sec.). Correction MRs to roll, however, were slower than MRs on correct responses, $\underline{F}$ (1, 26) = 6.14, $\underline{p} < .05$ (4.3 vs. 5.0°/.05 sec.). These

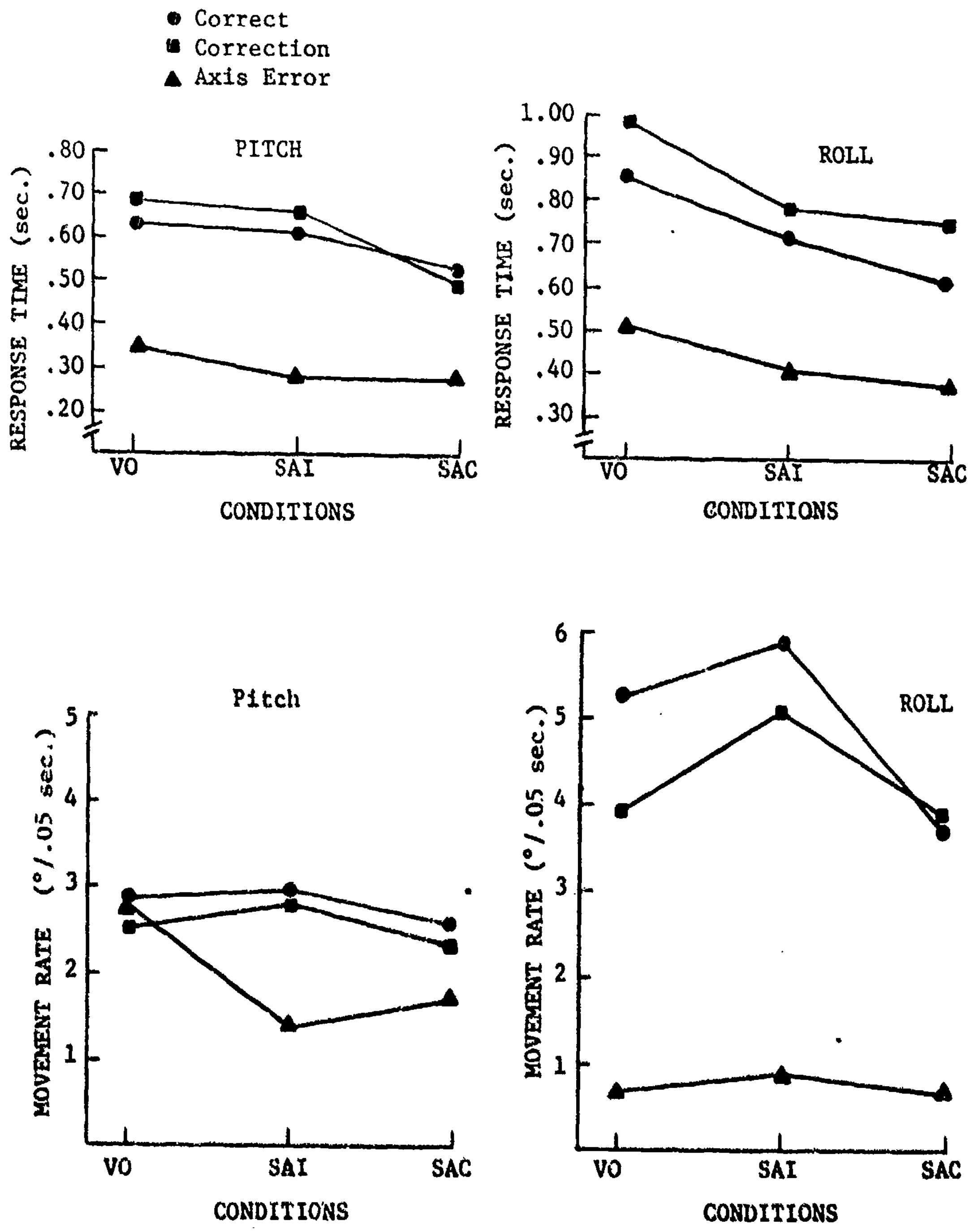

Figure 20. Response time and movement rate on correct responses, axis errors, and correction to errors as a function of conditions.

results contrast favorably with those found on reversals in which correction MRs were slower than correct ones, but on both axes.

In summary, the effects due to practice, conditions, experience, and axis on axis errors and corrections, as revealed by RT and MR measures, may be characterized as follows: (1) Although analyses were not carried out to determine the effects of practice on RTs and MRs on axis errors, there were no observable trends. (2) The VO condition resulted in longer RTs on both pitch and roll than SAI and SAC. These results are similar to those of RTs on correct responses to roll axis stimuli. While reversal responses did not show an effect due to conditions, there was a tendency for VO to result in slower RTs. Movement rate was faster in VO than SAI and SAC, but this was limited to the pitch axis. (On both correct responses and reversal errors, there was a tendency for MR to be faster in SAI.) (3) As was found on reversal errors, RTs and MRs did not result in differential effects due to experience. (4) Response time on axis errors was shorter to pitch than roll. In contrast to correct responses and reversal errors, MRs were faster to pitch than roll. (5) As with reversals, RTs on axis errors were shorter than on correct responses and MRs were slower, on both axes. (6) Correction RTs to axis errors showed an effect due to conditions. The pattern was similar to correct responses, in which SAC RT was shorter than VO and SAI on pitch, and RT to VO was longer than to SAI and SAC on roll. A similar pattern, though not statistically significant, was found on correction RTs to reversals. In contrast to axis errors, RTs to the corrections resulted in a significant effect

due to experience, with pilots having shorter RTs than non-pilots. Correction RTs to pitch were shorter than to roll. In contrast to RTs, there was no effect on correction MRs due to conditions, although there was a tendency for MRs to be faster in SAI than VO and SAC. (This finding compares favorably with MRs on correct responses and reversal errors. It will be recalled that correction MRs to reversals were significantly faster in SAI.) As found with correct responses and correction MRs to reversals, there was no effect due to experience. Correction MRs were slower on pitch than roll. (7) Correction RTs approached those of correct responses to pitch, but not roll. In both cases, however, correction RTs were longer. Similarly, correction MRs approached those of correct responses on pitch, but not roll. In both cases, however, correction MRs were slower than MRs on correct responses.

Motion Only (MO)

Responses to motion in an environment in which no visual stimuli (trials) occurred were, by definition, error responses. Nevertheless, subjects in all experience groups occasionally responded to motion inputs in this condition. The question addressed here is whether the characteristics of the responses that were made followed similar patterns to those in other conditions. Two types of responses were possible: "consistent" and "inconsistent." A "consistent" response was one in which axis and directionality of a control stick deflection was commensurate with the expected response to the specific motion function. Thus, a roll right motion would be responded to with a control stick deflection to the left. An "inconsistent" response was one in which the

control stick deflection was not commensurate with motion in axis and/or directionality. The analysis presented here is limited to "consistent" responses.

The relatively low number of responses to this condition (see Appendix F) precluded the possibility of determining effects of practice on RTs and MRs. Of greater concern was the pattern of responses. Mean RTs and MRs are presented in Table 13. In contrast to VO, SAI, and SAC, there were no differential effects due to experience, $\underline{F}$ (2, 9) = 1.88, $\underline{p} > .05$, or axis, $\underline{F}$ (1, 9) = 2.88, $\underline{p} > .05$. Similarly, MRs did not differ among experience groups, $\underline{F}$ (2, 9) = 1.24, $\underline{p} > .05$. There was, however, the typical axis effect, $\underline{F}$ (1, 9) = 7.47, $\underline{p} < .01$ in which MRs to pitch were slower than to roll (.5 vs. 2.1°/.05 sec.).

TABLE 13

Mean Response Times (in sec.) and Movement Rates (in °/.05 sec.) in MO

Experience groups	Pitch		Roll	
	RT	MR	RT	MR
Pilots	.44	.5	.49	1.2
Navigators	.40	.7	.28	3.2
Non-rated	.52	.4	.37	1.9

In summary, the results obtained on RT and MR measures were somewhat inconclusive. Obviously, the subjects in all experience groups responded to MO trials, but in the absence of visual stimuli the responses did not differ among these groups as might have been expected. Whether these results were due to the absence of visual stimuli is

difficult to ascertain. Possible avenues of interpretation will be explored later, under Error Rates.

Double Axis Incompatible (DAI)

As will be recalled, the DAI condition was experienced by pilots only. Accordingly, two sets of analyses of variance were carried out on the data. The first was limited to a within subjects design that treated this condition as a separate experiment. The second set of analyses compared DAI to VO, SAI, and SAC on pilot data only.

Correct responses. As found to be typical in all conditions and experience groups, practice did not have an effect on RT, F (3, 9) = .02, p > .05. Response time to pitch was shorter than to roll, F (1, 3) = 23.02, p < .05 (.58 vs. .73 sec.). As shown in Table 14, the effect of presenting motion cues that differ in axis from the visual ones, is to lengthen RTs on both axes. A comparative analysis of RTs in DAI

TABLE 14

Mean Response Times (in sec.) and Movement Rates (in °/.05 sec.) on Correct Responses by Pilots

Conditions	Pitch		Roll	
	RT	MR	RT	MR
VO	.57	3.1	.70	5.1
SAI	.51	3.3	.58	5.8
SAC	.48	3.0	.54	3.9
DAI	.58	2.1	.73	4.0

with those of VO, SAI and SAC on pilots resulted in a significant effect due to conditions on pitch, $F\ (3, 12) = 4.34$, $p < .05$ and roll, $F\ (3, 12) = 5.14$, $p < .05$. Newman-Keuls tests revealed that RTs in DAI did not differ from VO and SAI on pitch ($p > .05$) and from VO on roll ($p > .05$).

As with RTs practice did not have an effect on MRs, $F\ (3, 9) = 1.11$, $p > .05$. The typical axis effect was not significant, $F = (1, 3) = 5.5$, $p > .05$, although there was a strong tendency for MRs to pitch to be slower than to roll (2.1 vs. 4.0°/.05 sec.). A comparative analysis of MRs in DAI with VO, SAI, and SAC (see Table 14) revealed that there was no effect due to conditions on pitch, $F\ (3, 12) = 1.0$, $p > .05$ or roll, $F\ (3, 12) = 1.2$, $p > .05$.

Reversal errors. The scattered and relatively few reversal errors made in DAI prevented the possibility of determining the effects of practice on RT. With sessions pooled, RTs on reversals were slightly faster to pitch than roll (.33 vs. .38), but the difference was not significant, $F\ (1, 3) = 1.0$, $p > .05$. A comparative analysis of RTs (see Table 15) in DAI with VO, SAI, and SAC on pilots did not result in a significant effect due to conditions on pitch, $F\ (3, 12) = 2.2$, $p > .05$ or roll, $F\ (3, 12) = .37$, $p > .05$. A comparison of RT on reversals with those on correct responses, revealed that the former was shorter, (.35 vs. .65 sec.), $F\ (1, 3) = 11.1$, $p < .05$ (with axis pooled). Correction RTs to reversals in DAI resulted in the typical axis effect, $F\ (1, 3) = 142.1$, $p < .05$ (.45 vs. .62 sec. on pitch and roll, respectively). A comparative analysis of correction RTs (see

TABLE 15

Mean Response Times (in sec.) and Movement Rates (in °/.05 sec.) on Reversal Errors by Pilots

Conditions	Pitch		Roll	
	RT	MR	RT	MR
VO	.38	1.4	.48	3.1
SAI	.37	1.3	.43	5.1
SAC	.24	.5	.35	2.0
DAI	.33	.7	.38	2.8

Table 16) in DAI with RTs in VO, SAI, and SAC, resulted in a significant effect due to axis, $\underline{F}$ (1, 11) = 6.36, $\underline{p}$ < .05, but conditions was not significant, $\underline{F}$ (3, 12) = 1.14, $\underline{p}$ > .05. As was found on correct responses, however, there was a tendency for correction RTs to be relatively long and not to differ from VO and SAI on pitch and from VO on roll. Finally, correction RT approached that of correct responses, $\underline{F}$ (1, 3) = 6.3, $\underline{p}$ > .05 (.54 vs. .65 sec., with axis pooled).

TABLE 16

Mean Correction Response Times (in sec.) and Movement Rates (in °/.05 sec.) to Reversal Errors by Pilots

Conditions	Pitch		Roll	
	RT	MR	RT	MR
VO	.51	2.3	.61	3.5
SAI	.48	3.5	.49	5.8
SAC	.36	2.6	.46	3.3
DAI	.45	1.7	.62	2.3

As with RTs, the effects of practice on MRs on reversal errors were not determined. With sessions pooled, axis was not significant, F (1, 3) = 6.2, p = .09, although there was a strong tendency for pitch to result in slower MR than roll (.7 vs. 2.8°/.05 sec.). A comparative analysis of MRs (see Table 15) in DAI with those of VO, SAI, and SAC on pilots failed to result in a significant effect due to conditions on pitch, F (3, 12) = 1.0, p > .05 and roll, F (3, 11) = 1.2, p > .05. A comparison of MRs on reversal errors with those on correct responses in DAI, revealed that MRs on reversals were slower than on correct responses, F (1, 3) = 31.95, p = .010 (1.6 vs. 3.1°/.05 sec., with axis pooled). Correction MRs to reversals in DAI did not result in the typical axis effect, F (1, 3) = 1.1, p > .05, but there was a tendency for pitch to result in slower MRs than roll (1.7 vs. 2.3°/.05 sec.). A comparative analysis of correction MRs (see Table 16) in DAI with those in VO, SAI, and SAC on pilots, resulted in a significant effect due to axis, F (1, 11) = 23.3, p < .01 and conditions F (3, 12) = 4.7, p < .05. The significant conditions effect was due to faster correction MRs in SAI than VO, SAC and DAI (p < .05) and there were no differences between the latter three conditions. Correction MRs to reversal errors did not approach those of correct responses, F (1, 3) = 22.8, p < .05, with correction responses remaining slower than correct ones (1.9 vs. 3.1°/.05 sec. with axis pooled).

<u>Axis errors</u>. Practice did not have an effect on RTs of axis errors in DAI, F (3, 9) = .05, p > .05. Although RTs to pitch were slightly shorter than to roll, the difference was not significant, F (1, 3) =

2.8, $p > .05$ (.44 vs. .49 sec.). A comparative analysis of RTs (see Table 17) in DAI with those of VO, SAI, and SAC on pilots, resulted in a significant effect due to conditions on pitch, F (3, 11) = 10.7, $p < .01$, but not roll, F (3, 12) = .9, $p > .05$. The significant effect on pitch was due to the longer RTs in DAI than VO, SAI and SAC

TABLE 17

Mean Response Times (in sec.) and Movement Rates (in °/.05 sec.) on Axis Errors by Pilots

Conditions	Pitch		Roll	
	RT	MR	RT	MR
VO	.30	1.9	.48	.8
SAI	.26	1.2	.37	.7
SAC	.28	1.6	.42	.4
DAI	.43	4.1	.49	1.2

($p < .05$) as revealed by the Newman-Keuls test. A comparison of RTs on axis errors with those on correct responses in DAI showed that the former were shorter, F (1, 3) = 9.97, $p < .05$ (.46 vs. .65 sec., with axis pooled). Correction RTs to axis errors in DAI resulted in the typical axis effect, F (1, 3) = 23.43, $p < .05$, with pitch resulting in shorter RT than roll (.62 vs. .84 sec.). A comparative analysis of correction RTs (see Table 18) in DAI with those of VO, SAI, and SAC on pilots resulted in the usual axis effect, F (1, 11) = 73.43, $p < .01$ and conditions was significant, F (3, 12) = 20.84, $p < .01$. Correction RTs in DAI did not differ from VO on either pitch ($p > .05$) or roll ($p > .05$) as revealed by the Newman-Keuls test. Finally, correction RTs approached those of correct responses on pitch,

F (1, 3) = 1.31, $p > .05$ (.61 vs. .56 sec.) and roll, F (1, 3) = 2.18, $p > .05$ (.84 vs. .73 sec.).

Practice did not have an effect on MRs of axis errors, F (3, 9) = .54, $p > .05$. Movement rates to pitch were faster than to roll, F (1, 3) = 19.73, $p = .02$ (4.1 vs. 1.2°/.05 sec.) as found to be typical of axis errors. A comparative analysis of MRs (see Table 17) in DAI with those of VO, SAI, and SAC did not result in a significant effect due to conditions on either pitch, F (3, 11) = 3.55, $p = .051$ or roll, F (3, 12) = 2.49, $p > .05$. There was, however, a tendency for MRs in DAI to be faster than in the other conditions, particularly on the pitch axis. A comparison of MRs on axis errors with those of correct responses did not result in significance, F (1, 3) = .34, $p > .05$ (2.6 vs. 3.0°/.05 sec.). Correction MRs to axis errors in DAI resulted in the typical axis effect, F (1, 3) = 30.4, $p < .05$ with MRs to pitch being slower than to roll (1.7 vs. 3.8°/.05 sec.). A comparative analysis of correction MRs (see Table 18) in DAI with those of VO, SAI, and SAC on

TABLE 18

Mean Correction Response Times (in sec.) and Movement Rates (in °/.05 sec.) to Axis Errors by Pilots

Conditions	Pitch		Roll	
	RT	MR	RT	MR
VO	.60	3.2	.81	4.4
SAI	.52	3.3	.57	5.9
SAC	.25	4.7	.68	5.5
DAI	.62	1.6	.84	3.8

pilots did not result in a significant effect due to conditions, F (3, 12) = 2.1, $p > .05$. There was, however, the usual axis effect, F (1, 12) = 5.35, $p < .05$, with MRs to pitch being slower than to roll (3.2 vs. 4.9°/.05 sec.). Finally, correction MRs approach those of correct responses on pitch, F (1, 3) = .69, $p > .05$ (2.9 and 2.8°/.05 sec.) and roll, F (1, 3) = .18, $p > .05$ (4.7 vs. 4.5°/.05 sec.).

In summary, the effects due to SAI on pilots, as revealed by RT and MR measures, may be characterized as follows: (1) Practice did not have an effect on RTs and MRs on correct responses and on axis errors. Possible effects on reversals were not determined, but there were no observable trends. (2) Response times to pitch on correct responses were shorter than to roll and MRs tended to be slower. There also was a tendency for this same relationship to exist on reversal errors. Similarly, there was a tendency for RTs on axis errors to be shorter to pitch than roll, but the difference was not significant. In contrast to reversals, MRs on axis errors were faster to pitch than to roll. (3) Response times on reversal errors were shorter than to correct responses and MRs were slower. Response times on axis errors were shorter than on correct ones, and MRs tended to be slower, but this difference was not significant. (4) Correction RTs to reversals were shorter to pitch than to roll and MRs tended to be slower. Similarly, correction RTs to axis errors were shorter to pitch and MRs were slower. (5) Correction RTs to reversals approached those of correct responses, but the MRs were significantly slower. Correction RTs and MRs to axis errors approached those of correct responses. (6) Response times on

correct responses in DAI did not differ from VO and SAI on pitch and from VO on roll. Movement rates on correct responses did not differ among conditions on either axis. These results compare favorably with those found on correct responses by the other experience groups. Similarly, RTs and MRs on reversals did not result in an effect due to conditions on either axis. Correction RTs to reversals did not differ among conditions, but MRs were faster in SAI. Response times on axis errors resulted in a significant conditions effect on pitch, but not roll (RTs in DAI were longer than in the other conditions on the pitch axis). Response times on axis errors did not differ among conditions on either axis. Correction RTs to axis errors resulted in a significant conditions effect. Response times in DAI did not differ from VO on either axis. Correction MRs did not differ among conditions.

Amendment Time

Amendment time was defined as the period needed by the subject to detect his own error. This measure was computed by subtracting the mean initial RT on reversal errors from the mean correction RT to these errors. In other words, amendment time is the time interval between the onset of an error response and the onset of the correction response to the error, as defined in the Experimental Procedure.

There were two major questions that stimulated the analysis of amendment time data. The first asked whether the previous experience of subjects influenced the amount of time needed to detect an error. The second was related to a possible reduction of error detection time

with practice. As will be recalled, the analysis was limited to the reversal errors made by the three experience groups in SAI. The mean amendment times on each of these groups, over sessions, are presented in Table 19. Experience failed to reach significance, $\underline{F}$ (2, 8) = 1.8, $\underline{p} > .05$, although there was a strong tendency for pilots to detect errors more rapidly than navigators and non-rated subjects (.10, .24, and .20).

TABLE 19

Mean Amendment Times (in sec.)[a]

Experience groups	Sessions							
	Pitch				Roll			
	1	2	3	4	1	2	3	4
Pilots	.18	.11	.07	.07	.18	.10	.10	.05
Navigators	.13	.41	.19	.15	.33	.18	.11	.08
Non-rated	.13	.17	.18	.06	.29	.13	.29	.13

[a]A .05 sec. update lag between control input and the response on the visual monitor was subtracted from the raw data.

To test the possibility that practice had an effect on amendment time, independent analyses of variance were carried out on data from each experience group. The results revealed that pilots detected their errors more rapidly with practice, $\underline{F}$ (3, 9) = 18.3, $\underline{p} < .01$. Although there was a tendency for navigator amendment times to shorten with practice, the analysis of these data failed to reach significance, $\underline{F}$ (3, 9) = 1.2, $\underline{p} > .05$. Similarly, practice tended to have an effect on amendment times of non-rated subjects, but the reduction did not

approach significance, F (3, 9) = 1.2, $p > .05$. Amendment times were about the same on both pitch and roll for each experience group and there were no significant interactions with practice.

The mean amendment times presented in Table 19 compare favorably with those reported by Higgins and Angel (1970). These investigators found that error correction time (i.e., amendment time) ranged from 83 to 122 msec. Similarly, Gibbs (1965) found a significant reduction in error correction time with practice (.24 vs. .11 sec. for early and late practice, respectively). While only pilot data revealed a significant reduction, amendment times (with axis pooled) in the present investigation (.18 vs. .05 sec. in Sessions 1 and 4, respectively) were similar to those reported by Gibbs. That pilots were able to reduce significantly the time needed to detect errors, in contrast to non-pilots, may have been due to their previously learned tracking skills. Some evidence for this assumption was found in the tendency for pilot amendment times to be shorter than those of non-pilots, even though the differences were not statistically significant.

Error Rates

Previous analyses revealed that RTs and MRs were independent of practice, but not conditions, experience, and axis. The intent of the present analyses was to determine whether similar effects existed in the proportion of reversal and axis errors made by the three experience groups tested in this investigation.

<u>Visual Only (VO) versus Single Axis Incompatible (SAI) versus Single Axis Compatible (SAC)</u>

<u>Reversal errors</u>. The first set of analyses considered the possible effects of practice on the proportion of reversal errors made by the subjects. Nine within groups analyses of variance were carried out on the proportion of reversal errors made over sessions, with axis pooled. The detailed results of the analyses are presented in Appendix I. As noted from the proportions presented in Table 20, reversal errors

TABLE 20

Proportion of Reversal Errors as a Function of Sessions

Conditions	Experience groups	Sessions									
		Pitch					Roll				
		1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$
VO	Pilots	.10	.10	.03	.07	.08	.16	.11	.09	.11	.12
	Navigators[a]	.10	.13	.03	.08	.09	.18	.24	.04	.04	.13
	Non-rated	.10	.07	.08	.08	.08	.23	.16	.12	.11	.16
	$\bar{X}$	.10	.10	.05	.08		.19	.17	.08	.09	
SAI	Pilots[a]	.39	.22	.09	.09	.20	.54	.52	.29	.28	.40
	Navigators[b]	.34	.11	.20	.12	.20	.36	.33	.13	.09	.23
	Non-rated[a]	.36	.19	.20	.15	.23	.34	.27	.18	.23	.25
	$\bar{X}$	.36	.17	.16	.12		.41	.37	.20	.20	
SAC	Pilots	.05	.06	.05	.03	.05	.06	.03	.05	.02	.04
	Navigators	.11	.06	.09	.08	.09	.14	.04	.07	.04	.07
	Non-rated	.13	.11	.11	.07	.11	.08	.09	.04	.04	.06
	$\bar{X}$	.10	.08	.08	.06		.09	.05	.05	.03	

[a]p < .05

[b]p < .01

declined significantly with practice in the SAI condition. Table 21 reveals that most of the learning effects in SAI occurred in the first session on the pitch axis and by the second session on roll. With the exception of navigators in VO, sessions was not a significant factor in VO and SAC. An examination of Table 20, however, will reveal that there was a tendency for all groups to make less errors with practice. Again, with the exception of navigators in VO, axis was not significant and there were no Sessions X Axis interactions in any of the nine analyses (see Appendix I).

TABLE 21

Percent Differences in Reversal Errors Between Sessions[a]

Experience groups	Session differences					
	Pitch			Roll		
	(1)-(2)	(1)-(3)	(1)-(4)	(1)-(2)	(1)-(3)	(1)-(4)
Pilots	17	30	30	2	25	26
Navigators	23	14	22	3	23	27
Non-rated	17	16	21	7	16	11

[a]Data obtained from Table 20, Condition SAI.

A between groups analysis of variance resulted in a significant effect due to conditions, $\underline{F}$ (2, 27) = 19.59, $\underline{p}$ < .01 (.11, .25, and .07 in VO, SAI, and SAC, respectively) and axis, $\underline{F}$ (1, 27) = 7.3, $\underline{p}$ < .05 (.12 vs. .16 on pitch and roll, respectively). As expected, incompatible visual-motion relationships resulted in a greater proportion of reversal errors. Although there was a tendency for subjects in VO to make more reversal errors than in SAC, a Newman-Keuls

test revealed that there was no difference between the two ($p > .05$). Experience was not a significant factor, F (2, 27) = .15, $p > .05$ (.14, .13, and .15 on pilots, navigators, and non-rated, respectively). It had been expected that the experience of pilots on compatible visual-motion relationships would result in having this group make a greater proportion of errors in SAI than non-pilots, but the Conditions X Experience interaction was not significant, F (4, 27) = .91, $p > .05$. Upon further examination of Table 20, however, it will be noted that the proportion of errors made by pilots in SAI on the pitch axis is greater than that of non-pilots in the first session and in all sessions on the roll axis. This finding suggested a possible Experience X Sessions interaction on the roll axis data, and possibly on the pitch axis. To test this possibility separate analyses of variance were carried out on pitch and roll data in the SAI condition. Neither of the expected interactions was significant; F (6, 27) = .71, $p > .05$ on pitch and, F (6, 27) = 1.1, $p > .05$ on roll. A possibility existed, however, that the relationship between previous experience and the amount of practice was not linear. An analysis of the linear and quadratic components on roll axis data revealed that the relationship was linear, F (1, 27) = 46.67, $p < .01$ and the Experience X Sessions interaction was not significant, F (3, 27) = 1.86, $p > .05$. In view of these results, it must be concluded that experience did not have an effect on the amount of reversal errors made by subjects as determined by the usual statistical tests. Nevertheless, the differences shown in Table 20 were deemed of sufficient importance to warrant

further investigation. To this end, the omega squared (ω^2) index (Hays, 1963, p. 323), a descriptive statistic, was applied to the data obtained from the three experience groups in SAI. This analysis was limited to roll axis data where the differences among groups was greatest. This index reflects the strength of association that exists between independent and dependent variables. In this respect ω^2 is similar to a correlation ratio. This index, however, can be applied to estimate the strength of association suggested by the differences in two means. In the present analysis, a large ω^2 would imply that a difference existed between the proportion of reversal errors obtained on two experience groups in a particular session. The estimated ω^2s are presented in Table 22 together with the differences between means of proportions from which ω^2s were computed. An examination of this table will show that the difference between pilots and navigators in the first experimental session was .17 (i.e., pilots made 17 percent more errors than navigators in Session 1). The difference in experience between pilots and navigators accounted for about 9 percent of the variance of their performance in Session 1. While this particular association is weak, the total pattern presented in Table 22 is noteworthy. The differences in experience between pilots and navigators accounted for some of the variance in all sessions, but especially the last. A similar association existed between pilots and non-rated subjects, but was limited to the first two sessions. Except for the last session, no difference existed between navigators and non-rated subjects. It will be noted that the differences in proportions of

TABLE 22

Omega Squared and Differences Between Means of Reversal Error Proportions for Each Experience Group Pair on Roll Axis Data in SAI

Sessions	Pilots vs. Navigators		Pilots vs. Non-rated		Navigators vs. Non-rated	
	ω^2	$(X_1)^a-(X_2)^b$	ω^2	$(X_1)-(X_3)^c$	ω^2	$(X_2)-(X_3)$
1	.087	.17	.100	.20	0	.02
2	.091	.20	.149	.25	0	.06
3	.090	.16	0	.11	0	-.05
4	.270	.19	0	.05	.34	-.14

[a] X_1 = proportion of errors by pilots

[b] X_2 = proportion of errors by navigators

[c] X_3 = proportion of errors by non-rated

errors are relatively consistent with these results. Thus, the results are suggestive of a weak association that can be attributed to the differences between pilots and non-pilots. In contrast to non-pilots, the experience of pilots tended to have a detrimental effect on performance.

To summarize, incompatible visual-motion relationships resulted in a greater proportion of control reversals by subjects in all experience groups, but slightly more by the pilots. There was a tendency for all experience groups to make more control reversals in VO than SAC, but the difference was not statistically significant. A larger proportion of reversal errors was made on roll than on pitch. The effect of practice was evidenced primarily by the reduction of reversal errors in SAI.

Axis errors. Nine within groups analyses of variance were carried out to determine possible effects of practice on the proportion of axis errors made by each group of subjects over sessions, with axis pooled. The detailed results of these tests are presented in Appendix J. Unlike reversal errors, practice did not have an effect on the proportion of axis errors made by any of the experience groups in any of the conditions. An examination of Table 23 will reveal a slight downward trend over sessions, but this trend was not found in all groups. Similarly, a

TABLE 23

Proportion of Axis Errors as a Function of Sessions

Conditions	Experience groups	Sessions									
		Pitch					Roll				
		1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$
VO	Pilots	.07	.03	.11	.07	.06	.06	.08	.07	.05	.07
	Navigators	.16	.03	.09	.11	.10	.14	.16	.13	.03	.10
	Non-rated	.07	.07	.07	.08	.07	.09	.08	.04	.07	.07
	$\bar{X}$	.10	.14	.09	.09		.10	.11	.08	.05	
SAI	Pilots	.08	.05	.06	.03	.05	.10	.04	.07	.14	.09
	Navigators	.12	.07	.04	.03	.06	.10	.03	.13	.08	.08
	Non-rated	.07	.09	.03	.10	.08	.23	.16	.11	.04	.13
	$\bar{X}$	.09	.07	.04	.05		.14	.08	.10	.09	
SAC	Pilots	.11	.01	.07	.04	.05	.08	.02	.07	.02	.04
	Navigators	.12	.09	.05	.03	.07	.15	.08	.08	.05	.09
	Non-rated	.06	.03	.00	.04	.03	.15	.15	.13	.12	.14
	$\bar{X}$	.10	.04	.04	.04		.13	.08	.09	.06	

between groups analysis of variance did not result in a significant effect due to conditions, $\underline{F}$ (2, 27) = .5, $\underline{p}$ > .05 (.08, .08, and .07 in VO, SAI, and SAC, respectively) or experience, F (2, 27) = 2.93, $\underline{p}$ > .05 (.06, .08, and .09 on pilots, navigators, and non-rated, respectively). Axis was significant, $\underline{F}$ (1, 27) = 5.4, $\underline{p}$ < .05 (.06 vs. .09 on pitch and roll, respectively).

The unsystematic scattering of axis errors was expected because the visual-motion relationships presented to subjects were always on the same axis. Differential effects due to sessions and conditions would have required an interpretation based on some form of unspecified, and perhaps uninterpretable, confusion of cues.

Reversal versus axis errors. An analysis was performed to determine whether differences existed between the proportions of reversal and axis errors. As expected, the proportion of reversal errors was greater than axis errors on both pitch, $\underline{F}$ (1, 27) = 16.28, $\underline{p}$ < .01 (.12 vs. .06) and roll, $\underline{F}$ (1, 27) = 21.91, $\underline{p}$ < .01 (.16 vs. .09). These differences, however, were not independent of conditions as revealed by a Conditions X Type of Error (i.e., reversal vs. axis error) interaction on pitch, $\underline{F}$ (2, 27) = 7.64, $\underline{p}$ < .01 and roll, $\underline{F}$ (2, 27) = 18.91, $\underline{p}$ < .01. As will be noted from the data presented in Table 24, the source of these interactions was the high proportion of reversal errors in SAI relative to axis errors in this condition.

TABLE 24

Proportion of Reversal and Axis Errors

Conditions	Errors	Pitch			Roll		
		Pilots	Navig.	Non-rated	Pilots	Navig.	Non-rated
VO	Reversal	.08	.09	.08	.12	.12	.16
	Axis	.06	.10	.07	.07	.10	.07
SAI	Reversal	.20	.20	.23	.40	.23	.25
	Axis	.05	.06	.08	.09	.08	.13
SAC	Reversal	.05	.09	.11	.04	.07	.06
	Axis	.05	.07	.03	.04	.09	.14

Motion Only (MO)

As will be recalled, an attempt to null the effects of motion in this condition was, by definition, an error response. While the proportion of these responses was small, it was important to determine whether those that were made followed a systematic pattern and could be regarded as actual responses to motion. Otherwise, it would be concluded that the data represented nothing more than random control stick inputs. In the analysis carried out on RT and MR measures, only "consistent" responses were given consideration. The present analysis compared the proportion of "consistent" with "inconsistent" responses. Presumably, a legitimate response to motion in the absence of visual stimuli would require that stick deflections be on the axis and direction commensurate with the motion function (i.e., "consistent" responses). Assuming that the subjects did respond to trials in this condition, the proportion of "consistent" responses should be significantly higher than "inconsistent" ones. Similarly, differential effects due to practice (i.e., a reduction

in the proportion of responses) and experience should be evident in the "consistent" response data. The proportion of responses of both types are presented in Table 25.

TABLE 25

Proportion of "Consistent" and "Inconsistent" Responses

Type of response	Experience groups	Sessions									
		Pitch					Roll				
		1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$
"Consistent"	Pilots	.15	.08	.12	.12	.13	.21	.16	.10	.12	.15
	Navigators	.20	.11	.03	.08	.11	.15	.09	.05	.06	.09
	Non-rated	.11	.11	.06	.09	.09	.08	.07	.11	.10	.09
	$\bar{X}$	.15	.10	.07	.10		.15	.11	.09	.09	
"Inconsistent"	Pilots	.00	.00	[illegible]	.01	.01	.05	.02	.00	.00	.02
	Navigators	.14	.06	.10	.01	.07	.07	.03	.08	.04	.05
	Non-rated	.06	.04	.03	.07	.05	.05	.03	.04	.00	.03
	$\bar{X}$	.07	.03	.05	.03		.06	.03	.04	.01	

Analyses of variance on each experience group and type of response, revealed that practice did not result in a reduction of responses over sessions. Also, there were no significant Sessions X Axis interactions. An examination of Table 25, however, will reveal a slight downward trend between the first and last experimental session on both types of responses, but "consistent" responses were made throughout all sessions. Between groups analyses of variance, by type of response, did not result in a significant effect due to experience on "consistent" responses, F (2, 9) = 1.1, p > .05 (.14, .10, and .09 on pilots, navigators, and non-rated, respectively), but approached significance on "inconsistent"

responses, $\underline{F}$ (2, 9) = 4.02, $\underline{p}$ = .056 (.01, .06, and .04 on pilots, navigators, and non-rated, respectively). Axis was not significant on either type of response.

If the past experience of pilots influenced their performance in this experimental condition, it would be expected that their responses be primarily on the "consistent" axis and direction, relative to motion. On the other hand, the absence of experience among non-pilots could result in a random distribution of responses between "consistent" and "inconsistent." An examination of Table 25 reveals that the differences between the two types of responses was somewhat greater for pilots than non-pilots. This finding suggested a possible Experience X Type of Response interaction. If such an interaction existed, then it could be concluded that the pilots tended to respond to motion and that the non-pilots responses were random. To test this possibility an analysis was carried out that compared response type with experience groups. The proportion of "consistent" responses was found to be significantly larger than "inconsistent" ones, $\underline{F}$ (1, 9) = 21.9, $\underline{p}$ < .01 (.11 vs. .04 on "consistent" and "inconsistent" responses, respectively) and the Experience X Type of Response interaction approached, but did not reach, significance, $\underline{F}$ (2, 9) = 3.45, $\underline{p}$ = .077. These results, however, were of sufficient interest to stimulate further analysis. Analyses of variance were performed to compare the two types of responses on each experience group separately. Pilots made significantly more "consistent" than "inconsistent" responses on both pitch, $\underline{F}$ (1, 3) = 20.74, $\underline{p}$ = .02 (.13 vs. .01) and roll, $\underline{F}$ (1, 3) = 16.83, $\underline{p}$ = .02 (.15 vs. .02). In

contrast to these results, there was a tendency for navigators to make more "consistent" responses than "inconsistent" ones, but the difference failed to reach significance on pitch, $\underline{F}$ (1, 3) = 1.9, $\underline{p}$ > .05 (.11 vs. .07) and roll, $\underline{F}$ (1, 3) = .91, $\underline{p}$ > .05 (.09 vs. .05). Similarly, non-rated subjects tended to make more "consistent" responses but the difference failed to reach significance on pitch, $\underline{F}$ (1, 3) = 1.1, $\underline{p}$ > .05 (.09 vs. .05) and roll, $\underline{F}$ (1, 3) = 3.37, $\underline{p}$ > .05 (.09 vs. .03). These results suggested that there was a strong tendency for pilots to respond to motion cues even though the expected visual ones were absent.

By responding to motion only, the subject provided an input which was fed back to him as a pitch or roll error on the visual display. This feedback should have been sufficient to affect learning, and therefore, to result in a strong downward trend of responding. Yet, all subjects, but primarily the pilots, responded to motion throughout all sessions. Obviously, motion provided a compelling cue that could not be easily disregarded.

Double Axis Incompatible (DAI)

Two sets of analyses were performed on the proportion of reversal and axis errors made by pilots. The first was a within subjects analysis that treated DAI as a separate experiment. The second set compared error rates in DAI with VO, SAI, and SAC on pilots.

Reversal errors. Practice did not result in a reduction of reversal errors in DAI, $\underline{F}$ (3, 9) = .22, $\underline{p}$ > .05. An examination of Table 26, however, will reveal that there was a slight reduction in

TABLE 26

Proportion of Reversal and Axis Errors by Pilots

Type of Errors	Sessions									
	Pitch					Roll				
	1	2	3	4	$\bar{X}$	1	2	3	4	$\bar{X}$
Reversal	.12	.07	.13	.06	.09	.01	.04	.03	.06	.03
Axis	.38	.33	.20	.24	.28	.46	.53	.54	.42	.49

errors by the fourth session on the pitch axis, but an increase on the roll axis. Thus, as expected, the distribution of reversal errors appeared to be unsystematic. Similarly, axis was not significant, $\underline{F}$ (1, 3) = 3.51, $\underline{p}$ = .16 (.09 vs. .03 on pitch and roll, respectively) and the Sessions X Axis interaction failed to approach significance, $\underline{F}$ (3, 9) = 1.1, $\underline{p}$ > .05. It is doubtful that the slight tendency for pitch to result in a greater proportion of reversals than roll is of any theoretical importance. That a roll motion was always associated with a visual pitch stimulus in this experimental condition should not mean that a greater proportion of reversal errors be expected to occur on the pitch axis because reversal errors, as defined here, are always associated with the same axis in which the visual stimulus occurred.

A comparative analysis was carried out on the proportion of reversal errors by pilots in DAI with those in VO, SAI, and SAC. There was a significant effect due to conditions, $\underline{F}$ (3, 12) = 14.33, $\underline{p}$ < .01. A Newman-Keuls test of the means revealed that this effect was restricted to the large proportion of reversal errors in SAI ($\underline{p}$ < .01) as compared

to VO, SAI, and SAC; there were no differences between the latter three conditions. Axis failed to reach significance, although there was a tendency for pitch to result in a smaller proportion of reversals than roll, F (1, 12) = 3.84, p = .07 (.10 vs. 15). As will be noted from the data presented in Table 27, there was a significant Conditions X Axis interaction, F (3, 12) = 6.34, p < .01, which resulted from the larger proportion of reversals on roll in SAI relative to pitch.

TABLE 27

Proportion of Reversal and Axis Errors by Pilots as a Function of Conditions

Conditions	Pitch		Roll	
	Reversal errors	Axis errors	Reversal errors	Axis errors
VO	.08	.06	.12	.07
SAI	.20	.05	.40	.09
SAC	.05	.05	.04	.04
DAI	.09	.28	.03	.49

Axis errors. Practice failed to have an effect on the proportion of axis errors made by pilots in DAI, F (3, 9) = 2.27, p > .05. An examination of Table 26 will reveal a slight downward trend on the pitch axis, but not on roll. Similarly, axis did not approach significance, F (1, 3) = 4.23, p > .05, although there was a strong indication that pitch resulted in a smaller proportion of errors than roll (.28 vs. .49). The Sessions X Axis interaction was not significant, F (3, 9) = 1.54, p > .05.

As with reversal error data, a comparative analysis was conducted on the proportion of axis errors made by pilots in DAI with those in VO, SAI, and SAC. Conditions was significant, F (3, 12) = 10.77, $p < .01$. A Newman-Keuls test revealed that this effect was due to the large proportion of axis errors in DAI ($p < .01$) as compared to VO, SAI, and SAC; there were no differences between the latter three. Axis was significant, F (1, 12) = 5.4, $p < .05$, with a larger proportion of axis errors being made to roll than to pitch (.17 vs. .11). While the data summarized in Table 27 suggested a possible Conditions X Axis interaction, this effect did not quite approach significance, F (3, 12) = 3.42, $p = .053$. Nevertheless, the significant axis effect appeared to be due to the relatively larger difference in the proportion of axis errors made to pitch and roll in DAI (.28 vs. .49), but not VO, SAI, and SAC.

Reversal versus axis errors. A comparison between the proportion of reversal and axis errors in DAI resulted in differences in the expected direction. There was a larger proportion of axis errors than reversals on pitch, F (1, 3) = 11.89, $p < .05$ (.28 vs. .09) and roll, F (1, 3) = 37.06, $p < .01$ (.49 vs. .03).

As will be recalled, the DAI condition was included in this investigation as an added feature to corroborate the predicted effects in SAI and to verify the notion that these effects were produced by visual-motion conflicts rather than by random control activities. Thus, it was predicted that the visual-motion relationships in SAI would result in a greater proportion of reversal than axis errors and that the converse would be true in DAI. Furthermore, it was anticipated

that the proportion of reversal errors would be larger in VO than SAC and that axis errors would not be a factor in these two conditions. To test these possibilities, an analysis of variance was carried out to compare the proportion of reversal errors with the proportion of axis errors made by pilots in VO, SAI, SAC, and DAI. Of particular interest in this analysis was a possible Conditions X Type of Error (i.e., reversal and axis errors) interaction. This analysis resulted in a significant interaction in the predicted direction on pitch, $\underline{F}$ (3, 12) = 3.72, $\underline{p} < .05$, and roll $\underline{F}$ (3, 12) = 31.26, $\underline{p} < .01$. Figure 21 illustrates these interactions on both the pitch and roll axes. Note that the characteristics of the relationships are preserved on both axes. The interaction effects were obviously due to a higher proportion of reversal errors occurring in SAI than DAI and a greater proportion of axis errors in DAI than SAI. The proportion of reversal errors was slightly higher in VO than SAC on both pitch and roll, even though neither was statistically significant, as revealed by Newman-Keuls tests. The overall results of this analysis confirmed the supposition that the distribution of the two types of errors over conditions would be systematic rather than random. It can be safely concluded that the two incompatible conditions (i.e., SAI and DAI) produced visual-motion conflicts and that these experimental conditions were independent with regard to their effects on the performance of pilots as measured by the two types of errors. Finally, it must be pointed out that only two percent of the axis errors in DAI were inappropriate to direction of motion (e.g., a control stick deflection to the right with a right roll

motion). As indicated earlier, these data were not included in the analysis.

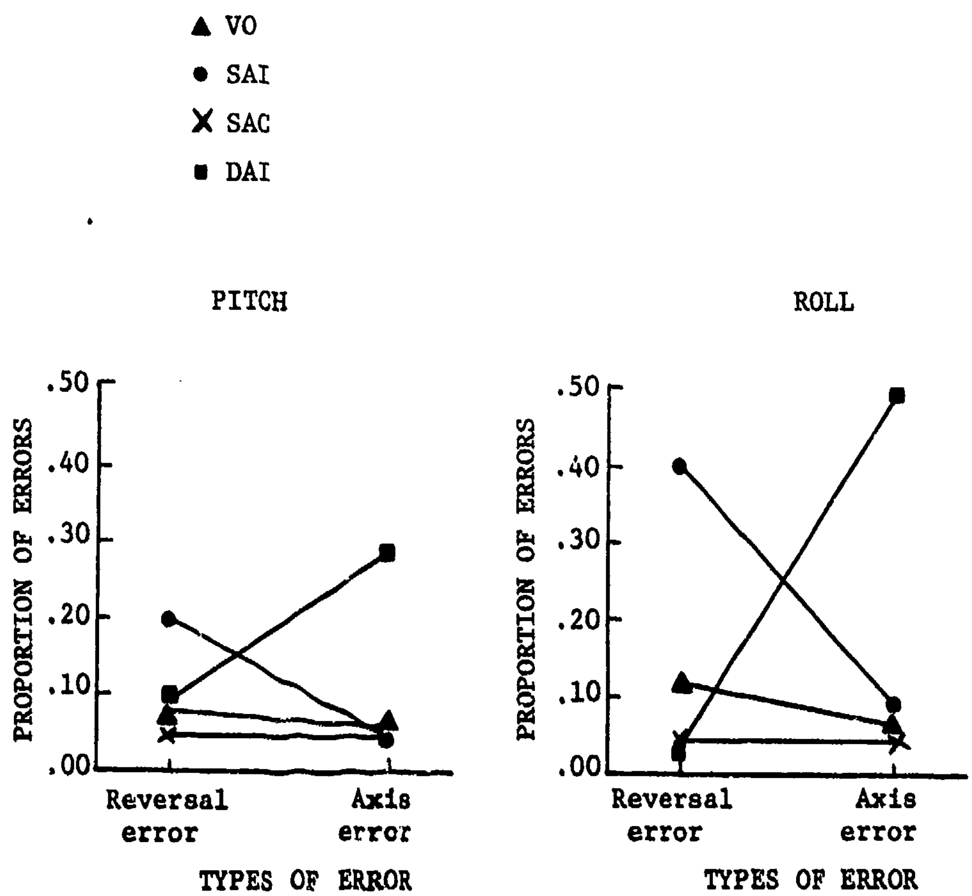

Figure 21. Proportion of errors made by pilots as a function of type of error and conditions. (Data points from Table 27.)

DISCUSSION

Main Experimental Effects

Effects of Visual-Proprioceptive Conflict

The results of this experiment revealed that the experimental conditions differed in their potential to produce visual-proprioceptive conflict. As expected, SAI had a profound effect on the performance of all subjects as measured by the proportion of reversal errors. Thus, it is concluded that the subjects were unable to disregard the effects of motion and that the visual-motion relationships in SAI were in conflict and interfered with the responses of the subjects, regardless of experience. Further evidence to substantiate this conclusion was found in the large proportion of axis errors made by pilots in DAI.

That reversal and axis errors resulted from differing visual-motion relationships represented by the experimental conditions rather than by random control stick deflections is substantiated from three sources. First, as expected the SAI condition resulted in a large proportion of reversals, but few axis errors. On the other hand, DAI resulted in a large proportion of axis errors, but very few reversals. Second, only two percent of the axis errors in DAI were <u>not</u> commensurate with the direction of motion. Third, there was a significant decline in the proportion of reversal errors over sessions in SAI whereas axis errors remained randomly distributed over session in VO, SAI, and SAC.

It had been anticipated that VO and SAC (no motion - motion comparisons) would differ in their potential to engender reversal errors. The presence of motion in SAC was thought to aid spatial orientation and result in a very small proportion of inappropriate responses. While the difference between these two conditions was consistently in the expected direction, it did not reach significance. Also, the proportion of reversal errors in these two conditions was relatively low and did not differ from the proportion of axis errors. This latter finding suggests that the errors in VO and SAC were random and non-task related. Although it is tempting to conclude that the visual factors provided the necessary information for spatial orientation and that motion in SAC served no useful role, the effect of motion was obviously present in SAI. Accordingly, the role of motion in SAC will not be dismissed. It must be recalled that VO did result in a strong and consistent tendency to produce more reversal errors than SAC. Detailed interpretation of these results, however, must be carried out in the light of other relevant data.

If motion plays an alerting role, then it is expected that the experimental conditions providing motion should result in shorter RTs than the one that did not (Matheny, et al., 1963). This assumption was confirmed. Response times on correct responses in VO were significantly longer than in SAC on both axes and also longer than SAI on the roll axis. It will be recalled that RTs on correct responses in SAI and SAC did not differ significantly, although there was a consistently strong tendency for SAC to result in shorter RTs on both axes. This tendency

is interpreted to mean that compatible visual-motion relationships provide alerting cues that aid performance. The failure to obtain a significant difference between SAI and SAC and the fact that RTs were longer in VO than SAI, however, would suggest that motion, even when it is incompatible (i.e., in conflict) with the visual stimulus, alerts the operator to changes in attitude.

The assertion that motion provides alerting cues cannot be generalized easily to the incompatible visual-motion relationships in DAI. Response times made by pilots on correct responses in this condition differed neither from VO and SAI on pitch nor from VO on roll. The relatively long RTs in DAI can be attributed to several factors. First, it will be recalled that the proportion of axis errors in DAI was high relative to SAI. This difference in errors may have been due to the disproportionate number of visual-motion stimulus alternatives in DAI as compared to SAI. It is assumed that adaptation to the visual-motion relationships in SAI was considerably easier than in DAI. In SAI the subject merely learned that a stick deflection in the opposite direction from the one provided by the motion cue would result in an appropriate response (i.e., the subject learned to deflect the control stick on the same axis and direction of the motion). Similar adaptation would have been difficult, if not impossible, in DAI because the visual-motion combinations were always on different axes and there were two alternative directions of motion displacement within each axis (i.e., a visual pitch up was accompanied with a roll right or roll left motion). Taking these factors into consideration, it can be safely

concluded that motion in DAI not only interfered with the pilot's response tendencies, but required that decisions be brought to bear on the task. The subject needed to select an appropriate response among the alternatives; a process requiring time.

Are the effects of conflict carried beyond the onset of a response? To test this possibility, analysis was carried out on the MR measures obtained on correct responses. Movement rates were essentially equivalent among conditions on pitch, but were slower in SAC on roll. This latter finding was not obtained in the comparative analysis where data obtained from pilots in DAI were compared to VO, SAI, and SAC, although there was a strong tendency for SAC to result in slower MRs on roll. It is concluded that neither the absence of motion nor the presence of an incompatible relationship has an effect on the performance of subjects beyond the onset of the response. More will be said about this in later discussions.

To summarize, visual-motion relationships that are incompatible interfere with the subject's performance and result in errors and longer RTs. The absence of motion lengthens RT on correct responses, but results in a lower proportion of control errors. The short RTs in SAC on both axes and the short RTs in SAI on roll relative to VO, provide evidence favoring the alerting role of motion. Moreover, since the onset of both the visual and motion stimuli occurred simultaneously, the results are consistent with the assumption (but do not necessarily imply) that proprioceptive cues derived from motion preceded, in time, the visual ones as had been reported by Matheny, et al. (1963). A

rough estimate of the possible contribution provided by the presence of compatible motion relationships to response time is obtainable by subtracting the average RT in SAC from the average RT in VO. This difference is found to be .11 sec. on pitch and .34 sec. on roll. A similar, but weaker contribution is found when VO is compared to SAI (.06 sec. on pitch and .13 sec. on roll).

The results provided compelling evidence in support of the assumption that motion cues play more than an alerting role in the subject's attempt to cope with visual-proprioceptive conflict. The large proportion of reversal errors in SAI in contrast to DAI and the large proportion of axis errors in DAI relative to SAI suggests that motion also provided directional information (see Figure 21). Moreover, that the overwhelming number of axis errors in DAI were commensurate with the direction of motion lends further support to this conclusion.

Effects of Experience

It was anticipated that the overlearned responses associated with conventional flying tasks would interfere with pilot performance under conditions of conflict. (Recall that the control-display relationship remained unaltered in this experiment. The incompatibility existing in SAI and DAI was a function of motion.) On the other hand, if pilots are able to ignore the effects of motion, then the absence of motion or the presence of visual-motion relationships that are incongruent with normal flying operations should have little effect on pilot performance. Similarly, the pilots should have no difficulty in the condition in which only motion cues were present (i.e., MO). If the visual-motion

relationships represented in SAC must be learned (i.e., performance in SAC is dependent on learned habits peculiar to pilots), then the performance of non-pilots should be worse in this condition. It was thought that the relative ease, or difficulty, with which non-pilots (but particularly the non-rated subjects) were able to respond appropriately in each experimental condition should provide some insight into the visual-motion relationship that would produce effective spatially oriented behavior among most of the population (i.e., is representative of a population stereotype).

The results revealed that the proportion of errors among the three experience groups was roughly equal. The expected difference, as might have been revealed by a Conditions X Experience interaction was absent. It was noted, however, that pilots in SAI made more reversal errors on the roll axis than non-pilots (.41 vs. .24). A descriptive statistic on these data showed that the visual-motion relationships in SAI had greater impact on pilots than non-pilots. These results must be interpreted with caution. It can be safely concluded, however, that pilots were unable to ignore the effects of motion and that previous exposure to flight conditions did not aid them in overcoming the effects of cue conflict. In fact, it was surprising to find that the pilots made occasional errors even when the visual-motion relationships were commensurate with those encountered in contact flying. Equally surprising was that the proportion of errors made by non-pilots in SAC were only slightly, but not significantly, higher than those of pilots. Moreover, a similar relationship was found in VO.

That reversal errors persisted in the compatible condition, in spite of the extensive experience of pilots, suggests that these subjects adopted a frame of reference in which the video display was interpreted as an artificial horizon indicator rather than a scene analogous to contact flying. Such an interpretation seems untenable for several reasons. First, more errors were made in SAI than SAC and VO by virtually all the subjects, even though the control-display relationships were precisely the same. Second, post-experimental debriefings revealed that pilots were painfully aware that the visual-motion relationships in SAI were in conflict with those of normal flying operations. Non-pilots, on the other hand, were unaware that there was something out of the ordinary, yet all of them made more reversal errors in SAI than SAC. It will be recalled that Jacobs and Roscoe (1975) obtained similar comments from flight naive subjects. Accordingly, the errors made by pilots in SAC can be attributed to factors of attention or motivation and those of non-pilots to their inexperience. If this interpretation is accepted, then it follows that the visual-motion relationships in SAC were compatible with the visual-proprioceptive sensations that engender adequate spatial orientation. Such relationships do not interfere with response tendencies, regardless of the experience of subjects.

Obviously, motion provided compelling cues to subjects in all experience groups, but primarily to the pilots. Further evidence that motion had a greater effect on pilots than non-pilots comes from the observed tendency for pilots to respond to motion cues even when visual

ones were absent in MO. The three groups made about the same proportion of "consistent" responses relative to motion, but the non-pilots made many "inconsistent" ones (i.e., responses that were not commensurate with the motion function) while pilots did not.

The previous experience of pilots (or factors due to selection) did not aid them to overcome the effects of visual-proprioceptive conflict as measured by the proportion of reversal and axis errors, but it did help them to reduce their response latencies. Pilot RTs on correct responses were considerably, and significantly, shorter than those of non-pilots. It had been thought that navigator RTs would be shorter than those of inexperienced subjects, but the differences were not significant. Apparently, the types of tasks conducted by navigators did not transfer positively to those in this experiment. The stimulus relationships represented in VO, SAI, and SAC had about the same effect on all subjects, regardless of experience. Finally, the MR following the onset of correct responses did not differ among the experience groups. Once a response is initiated, the rate of control stick deflections associated with the early phases of stimulus error correction is not affected by experience. While stick deflections beyond the point where MR was computed on correct responses were not analyzed, observation of the subjects revealed that all were fully able to null input errors and continue the task in accordance with instructions.

In summary, the results present a rather dismal picture of man's capability to function adequately under the conditions simulated in this

experiment. All subjects appeared to make use of motion and had difficulty responding appropriately when these cues were in conflict with visual ones. Furthermore, each subject in this experiment was exposed to a single condition in which rate and amplitude of the stimuli did not vary; a rather ideal situation. Isolated instances of the visual-motion relationships as experienced by subjects in this experiment could occur in an operational environment. Nevertheless, an operator of a remotely piloted vehicle would need to adapt to continuous changes in angular acceleration in one or more axes to the vehicle and/or the airborne station. Accordingly, he must learn to restrict his manual activities to visual information rather than to accept some mix of the vehicle status with that of the station. Whether operators can learn to disregard the effects of motion in these environmental conditions is a matter for research. That practice has a positive effect is the subject of the topic discussed next.

Effects of Practice

The history of research in the area of learning has shown that man is capable of improving his motor skills with practice. Thus, it was safe to assume that at least some learning would occur among the subjects in this experiment. In view of the conclusions reached in the preceding paragraphs, the importance of learning factors to the operation of remotely piloted vehicles cannot be overlooked. The primary question, however, dealt with the specific characteristics of improvement in performance and with the particular dependent variables affected. A related question asked whether motion was necessary for training future operators.

It was predicted that the effect of practice should be evidenced primarily in those conditions most conducive to visual-proprioceptive conflict. In view of the results discussed earlier, SAI and DAI were expected to result in the greatest amount of learning. Moreover, since roll creates the severest problem to spatial orientation, it was anticipated that practice would be most evident on responses to stimuli on that axis. These predictions were confirmed. The proportion of reversal errors made by subjects in all experience groups in SAI declined significantly with practice. Most of the learning in SAI occurred by the end of the first session on pitch control and by the second session on roll. The latter reveals that acquisition of skills was more difficult when the stimuli were presented on the roll axis than on pitch. It is noteworthy that virtually all subjects continued to make control reversals on the last session. The rate of decline over sessions suggested that considerable learning took place. Had the test continued for an undetermined number of sessions, the proportion of errors might have declined even further. Unlike SAI, however, learning failed to occur among pilots in DAI. Axis errors declined slightly over sessions on pitch control, but the errors were distributed about evenly on roll. Thus, it is impossible to determine from these data whether continued practice in DAI would have aided the subjects. Since faster learning occurred to pitch in SAI and there was a slight decline in axis errors to pitch in DAI, it is assumed that extensive practice would eventually result in learning. As noted earlier, the difference in learning rate between SAI and DAI may have been due to the

disproportionate number of visual-motion stimulus combinations between the two conditions thereby making the task in DAI more difficult.

It was anticipated that the absence of motion in VO would result in more reversal errors than the compatible relationships in SAC. Thus it was assumed that more learning would occur in VO than SAC, at least among the pilots. While there was a strong tendency for all subjects to make more reversals in VO, only navigators showed a significant practice effect in that condition and none showed an effect in SAC. Apparently, learning occurs only under circumstances of severe spatial disorientation.

While the difference in the proportion of errors made by pilots and non-pilots was not significant in MO, there was a strong tendency for pilots to make more "consistent" responses than "inconsistent" ones than non-pilots. Moreover, there was a strong tendency for pilots to make more reversal errors in SAI. These results suggested that practice should have greater effect on pilots than non-pilots in these two conditions. Some evidence for this assumption was revealed by the omega squared indices applied to roll axis data in SAI. The difference between pilots and non-pilots was maintained throughout all sessions, but the difference between navigators and inexperienced subjects was minimal. Observation of pitch axis data (see Tables 20 and 21) reveals that pilots tended to reduce the incidence of reversals at a higher rate than non-pilots. With axis pooled the reduction of errors from Session 1 to 4 was 28%, 25%, and 16% for pilots, navigators, and inexperienced, respectively. A similar relationship was not forthcoming in MO. There

was a reduction in the proportion of "consistent" responses to motion among pilots and navigators, but not among the inexperienced subjects. It must be recalled that both non-pilot groups also made an equal proportion of "inconsistent" responses in this condition, but the pilots did not. Accordingly, it is cautiously concluded that the reduction of responses among pilots represented an attempt to ignore the effects of motion. While non-pilots tended to reduce both "consistent" and "inconsistent" responses, this effect cannot be justified solely on the basis of legitimate responses to motion (i.e., responses that are commensurate with the direction of the motion function).

Unlike reversal errors, there was no evidence that RTs to correct responses changed with practice, regardless of experience. That RT remains stable on certain kinds of tracking tasks had been reported earlier by Gottsdanker (1956). Yet pilot RTs were consistently shorter than those of non-pilots in all conditions, but there was no difference between the two non-pilot groups. Either the number of trials in this experiment was insufficient to effect a change or the short RTs made by pilots was due to selective factors. Finally, the MR following the onset of a response was unaffected by practice. It might be argued that the number of trials was insufficient to be revealed in changes to MR measures. Since MRs did not differ significantly among the three experience groups in any of the conditions, it is safely concluded that an increase in the number of trials would not have resulted in changes.

To summarize, it is apparent that the effects of practice on performance is predicated on the potential of visual-motion relationships

to produce conflict. As expected, pilots tended to be affected by the incompatible relationships more than non-pilots and show a greater effect due to practice. The number of test sessions, however, was insufficient to reduce errors in SAI and DAI to the level of SAC.

Can non-pilots be assigned to operate remotely piloted vehicles? The answer to this question is a cautious yes. While the various visual-motion relationships used in this experiment had about the same effect on all experience groups, the non-pilots tended to make less errors in SAI than pilots despite their lack of experience or familiarity with flight operations. It could be argued that pilots have the advantage of flight experience. Under stress, however, the pilot may revert to old habits and respond to attitude changes of the airborne station. A related question asks whether pilot performance would deteriorate upon return to flying status. The results of this and other experiments have shown that motion is an important factor in pilot performance. If a pilot is trained to disregard the effects of motion in order to operate remotely piloted vehicles from an airborne station, the effect of this training could have dire consequences if he is returned to flying status. While problems in flight usually arise when the aircraft accelerations are below threshold, training to ignore sudden changes in attitude compounds the problem.

This experiment has shown that under the conditions tested, motion provides alerting and directional cues. Yet the operator of a remotely piloted vehicle must ignore these cues and place full confidence in the visual display. The extent to which confidence can be instilled in

prospective operators might depend on their previous experience with these displays. If a display has caused a pilot to experience conflict, there may be a greater possibility that he will experience these same conflicts. Finally, whether pilots or non-pilots are selected, the results of this experiment strongly suggest that the operators be trained in the presence of motion cues.

Effects of Axis

Previous studies have shown that there is a persistent superiority in performance when visual stimuli are horizontal or vertical rather than oblique. As indicated in the Introduction this phenomenon was referred to as the oblique effect by Appelle (1972). Other studies conducted on judgments of the vertical when the subject and the stimulus are tilted laterally in the same or opposite directions have shown that perception of body posture becomes equivocal. Finally, it has been known for many years that problems in interpreting the direction of attitude shown on aircraft artificial horizon displays are greater on roll than pitch. In his analysis of pilot errors, for example, Fitts & Jones (1947) found that of 22 reversal errors 19 were due to misinterpreting the direction of bank.

Judging from the studies cited above, and others discussed in the Introduction, it was assumed that differential effects would result from visually displayed pitch versus roll. This assumption was overwhelmingly confirmed.

Overall, there was a greater proportion of reversal errors on roll than on pitch (.16 vs. 12), but this difference was attributed to VO (.13 vs. .08) and SAI (.30 vs. .21). No difference was found in SAC (.06 vs. .08). It will be recalled that the effects of practice were observed primarily in VO and SAI and this effect was mainly on roll control. Apparently the effect disappears whenever compatible visual-motion relationships are present as in SAC. (This finding does not mean that the compatible relationships in SAC did not present problems to the subjects. Reversal errors were made by all subjects in all experience groups throughout all experimental sessions.) In a study comparable to VO, Kelley, et al. (1961) reported similar findings and noted that it was easier for display content to become the frame of reference for pitch than for roll displacements.

It is of interest to note that the effect produced by visually displayed roll in VO, SAI, and SAC persisted on axis errors. While the difference was small (.06 vs. .09) it was nevertheless significant. Elsewhere, the distribution of axis errors in these three conditions was unsystematic. In DAI the expected axis effect demonstrated by pilots was significant, with a higher proportion of axis errors made to visually displayed roll than pitch (.49 vs. .28). The difference in the proportion of reversal errors was not significant. These findings lend further support to the assumption that motion in DAI interfered with the subject's response tendencies to control-display relationships. Moreover, the results suggest that motion interferes with visually mediated orientation. Had the visual stimulus interfered with the

responses to motion, then more axis errors would have been made to visually displayed pitch in which the motion function was roll. From these results, it is tempting to conclude that spatial orientation is mediated primarily by visual factors rather than gravity. This is certainly not the case here. It must be recalled that the experimental task required that subjects rely on visual cues; control stick deflections were totally independent of motion. Nevertheless, motion cues were extremely compelling to pilots. Even when these cues were provided in the absence of visual ones the pilots responded to motion. Support for this conclusion was found in the differential axis effect on pilot "consistent" responses to MO. While non-pilots did not show differences (an additional evidence that the responses of non-pilots in MO were random, but not those of the pilots), the pilots made a higher proportion of responses to roll motion than to pitch (.15 vs. .12).

Previous investigations have shown that discrimination RT is shorter to horizontal and vertical lines than to obliques. This effect is preserved even when the head is tilted 45° right or left (Attneave & Olson, 1967). Thus, it was expected that visually presented roll would result in longer RT than pitch, regardless of conditions or experience. This prediction was overwhelmingly supported in the experimental results. Response time to correct responses were consistently and significantly longer on roll. Similarly, pilot RT in DAI revealed precisely the same axis effect. Finally, further evidence was found to support the notion that pilots made legitimate responses to motion in MO while non-pilots did not. Response time of pilots to roll

motion was longer, though not significantly, than to pitch whereas the opposite was the case with non-pilots.

Conditions, experience, and practice had little effect on performance beyond the onset of correct responses (i.e., MR). Axis, on the other hand, had a profound effect on MR, regardless of conditions, experience and practice; MR on roll control was always faster than on pitch. When this finding is taken together with the results obtained on RT measures, an interesting relationship develops: Mean RT is shorter and mean MR is slower to pitch than to roll. All variables in this experiment that engendered short response latencies were followed with slow corrective movements. This relationship is given more detailed attention in later discussions.

In summary, it is apparent that visually presented roll presents greater problems to spatial orientation than pitch. Response times are longer and more errors are made on roll. Except for the rather novel relationship between RT and MR, the results are in substantial agreement with findings reported by several investigators.

<u>Effects of Conflict, Experience, and Axis on Error RT and MR</u>

While motion served to alert the subject to the changing status of the station, as determined by RT to correct responses, similar evidence appeared to be present on reversal and axis errors, but was very weak. There was a tendency for RTs on reversals to be somewhat longer in VO than SAI and for SAI RTs to be longer than SAC, particularly on roll control, but the differences were not significant. A similar pattern

was observed on axis errors, but here RT in VO was significantly longer than SAI and SAC on both axes. Reversal errors made by pilots did not reveal a significant effect due to conditions, but the axis errors were significantly longer in DAI than VO on pitch but not roll. When an error is to be executed, the absence of motion in VO tends to lengthen the onset of a response, but the data were not compelling in this regard. Similarly, the relatively strong effects due to experience were not observed on RTs associated with reversal and axis errors. There was an extremely small tendency for pilot RTs to be shorter than those of non-pilots on both types of errors, but the differences were not significant.

Unlike RT, the results obtained from MR measures on reversal and axis errors were similar to those on correct responses. Neither conditions nor experience had an effect on the MRs associated with reversals. There was a small, but significant effect due to conditions on axis errors: VO resulted in faster MRs than SAI and SAC on pitch, but not roll. Typically, MRs in VO tend to be slightly slower than in SAI (see Figures 19 and 20). Thus, it is impossible to determine whether this finding was due to systematic effects stemming from the absence of motion in VO or to some uncontrolled and unidentifiable factor. When MRs in DAI were compared to those of the other conditions there were no differences on either axis. Accordingly, it is concluded that the MR on correct and error responses are not affected by the same variables that have an effect on RT to correct responses and possibly to errors.

Previous analyses revealed that the oblique effect was a strong factor influencing RT and MR on correct responses, regardless of conditions, experience, and practice. Response time was found to be longer and MR faster on roll control than on pitch. There was a reason to believe that this same relationship would prevail on reversal errors. This assumption was confirmed; reversal error RT was significantly longer and MR slower on pitch than roll. Axis errors, on the other hand, resulted in a different pattern. While RTs on axis errors in VO, SAI, SAC, and DAI were always longer on roll, MRs were always slower. It must be recalled, however, that axis errors represented stick deflections on the axis that did not correspond to the axis of the visually displayed stimulus. Thus, when the visual stimulus was roll, the subject responded with a pitch control, creating an axis error. Movement rates on pitch control, whether associated with correct or error responses, were found to be typically slower than on roll control. More will be said about this effect in the discussion that follows.

Effects of Conditions, Experience, and Axis on Error Correction

After an error has been committed, a corrective action is taken to null the effects of the error produced by the stimulus as well as the error added by the subject's control input. It was of interest to determine whether error correction RT and MR followed the same or a similar pattern found on correct responses.

Visual and motion stimuli were in progress, but not necessarily terminated, when correction activities were initiated. Accordingly, the question asked was whether the effect due to visual-proprioceptive

conflicts revealed on correct responses would apply to corrections. There was a slight tendency for correction RT to reversals to be longer in VO than SAI and SAC, although the difference was not significant. Similarly, correction RT to reversals in DAI did not differ from the other conditions. Correction RT to axis errors, on the other hand, was significantly longer in VO on both axes and DAI correction RT did not differ from VO, as had been found on correct responses. That correction RT to reversals was slightly longer in VO and significantly longer on correction to axis errors suggests that the absence of motion in VO had similar effects as those found on correct responses. The presence of motion in SAI, SAC and DAI also had similar effects. It might be argued, however, that the lack of compelling differences as had been found on correct responses can be attributed to the temporal period in which the corrections are initiated. That is, corrections begin at a point where the physical effects of the visual and motion stimuli are terminated. This argument appears untenable for several reasons. First, RTs on errors were typically shorter than those on correct responses, regardless of conditions, experience or axis. Second, when RTs to the correction of reversal errors were compared to those of correct responses, there were no differences. Correction RTs to axis errors were slightly longer than RTs on correct responses on roll, but not pitch. Overall, the results suggest that a minimal time period is required for processing information necessary to effect a correct response. More will be said about these two factors in a later discussion.

Correction MR to reversal and axis errors in VO, SAI, SAC, and DAI revealed a similar pattern to that found on correct responses. That is, the differences among conditions were generally not significant. Movement rates on reversal and axis errors were typically slower than those of correct responses. When correction responses to reversal and axis errors were compared to MR on correct responses it was found that the corrections remained slower, but were faster than the errors. It is therefore concluded that MRs on correct responses, whether originally correct or whether associated with corrections, are faster than MRs on errors.

Correction RTs and MRs have other characteristics in common with originally correct responses. Pilot RT was significantly shorter than that of non-pilots on corrections to reversal and axis errors and correction MRs failed to show differences among experience groups. Finally, correction RTs to both types of errors were shorter and MRs were slower on pitch than roll. The latter represents a complete shift from MR on axis errors. It will be recalled that MRs on axis errors were faster on pitch than roll, but the opposite was the case on correct responses. Upon correction of an axis error, the stick deflection again corresponds with the visual stimulus rather than motion. It had been noted in the Results that the axis effect found on MRs of axis errors was probably due to differential muscular forces rather than to conflict with the visual stimulus (i.e., roll control always results in faster MRs).

Theoretical Considerations

Correct Versus Error Responses

When RTs associated with correct responses are compared to those of errors, a very interesting relationship unfolds: It is always the case that the RTs on reversals and axis errors are shorter than RTs on correct responses, regardless of conditions, experience, or axis. This effect is not peculiar to the present tracking task. Previous research on choice reaction time has shown that error RTs are usually shorter than correct ones (Egeth & Smith, 1967). An exception to this finding was reported by Fitts (1966). Using a task that had subjects adapt to changes in speed versus accuracy, it was found that the speed group responded with shorter RTs than the accuracy group and made more errors, but RTs to errors did not differ from RTs to correct responses. More recently, Hale (1969) had subjects adopt speed or accuracy sets in a self-paced serial reaction task. He found that error responses were consistently shorter than correct ones. This effect was explained in terms of a serial classification model in which RT is viewed as being composed of a series of classification steps. When this process is terminated early, a random choice is made from the alternatives and an error may occur. It was claimed that this random choice occurs faster than the classification steps; therefore, the RTs associated with errors are shorter. In a different experiment, Hale (1968) gave subjects conflicting instructions to maximize speed and minimize error in a serial choice reaction task with two, four, and eight alternatives. Response times on errors were shorter than on correct responses, but

RTs on errors varied in the same way as RTs on correct ones. Both the correct and error RTs were lengthened with increasing number of alternatives and both shortened with practice.

In an experiment more closely related to the present one, Gibbs (1965) found that step-input tracking RTs on directional errors varied in accordance with stimuli of unequal probabilities (the direction of the step input depended on a preselected set of probabilities). Response times on directional errors were longer than on correct ones when the direction of the step was unequivocal. A similar finding was reported also by Angel and Higgins (1969) with steps of equal probability. When the direction of the step was improbable, however, Gibbs found that the RTs on directional errors were shorter than on correct responses and the two were virtually identical on equiprobable steps. Gibbs expressed surprise with the results obtained on unequivocal steps because they were not in the expected relation between accuracy and speed. It is possible, however, that this finding was due to confounding speed and accuracy (i.e., "respond as rapidly and as accurately as possible") and forcing the subject to make an undefinable tradeoff when the steps were improbable. With unequivocal steps the subjects made less errors and the conflicting instructions may not have had an effect. It is suggested here that to reduce errors while at the same time respond as rapidly as possible, the subjects relied heavily on anticipatory behavior. In fact, Gibbs reports that anticipatory movements were common in the subjects who made the most errors.

In the present experiment, an effort was made to insure that conflicting sets for speed and accuracy did not occur. The stimulus probability was equiprobable as in Gibbs' experiment except that there were more alternatives to choose from. Yet RTs to reversals and axis errors were consistently shorter than correct ones, rather than identical. There was a tendency for reversal error RTs, and a stronger tendency for axis error RTs, to be subject to the same variables that influenced correct responses. Moreover, the axis effect on both types of errors was extremely compelling.

Why are error responses shorter than correct ones and why do they seem to obey the same rules governing correct responses? An answer to the first part of the question may be sought in terms of the subject's behavior during the period immediately preceding the onset of the stimulus event. It was already mentioned that Gibbs' subjects made small anticipatory movements before the stimulus onset. If a subject is set for speed and the stimulus event is improbable, his haste to respond engenders errors with short latencies. The amount of processing of information prior to the stimulus event may account for the short RTs on these errors.

While anticipatory behavior may account for the short RTs on errors, it does not provide a complete answer to the second part of the question posed at the beginning of the preceding paragraph. To determine why error responses seem to be subject to the same variables as correct responses, the nature of the anticipatory behavior must be explored further. Adams and Creamer (1962) distinguished between responses that

benefit from anticipation and those that result from premature anticipation. The former infers that anticipatory mechanisms are initiated prior to the onset of the stimulus and result in superior tracking performance. Responses that are prematurely anticipatory, however, are claimed to result in poorer performance. While these investigators applied these terms to continuous tracking tasks, rather than to step inputs, a combination of these two forms of anticipation may serve to explain the results obtained in the present experiment.

In some respects the task required of subjects can be likened to classical reaction time tasks. When the subject awaits the onset of the stimulus event errors are less likely to occur, but the latency is expected to be considerably longer. Beneficial anticipation allows him to predict when a stimulus event is to take place and to select the most probable response among the possible stimulus alternatives. When response selection is initiated prior to the time that anticipatory processes are complete the subject may likely respond prematurely and make an error. This does not mean that some beneficial anticipation did not occur. It simply claims that the process was terminated early. Accordingly, variables that had an effect on correct responses may appear also in the errors because some processing actually occurred. If this model of anticipatory behavior accounts for the results obtained in this experiment, then it would also predict that some correct responses would have short RT. That is, if the anticipatory process is terminated early, the selection of a response is roughly random (as claimed by serial classification models), but on occasions may result

in the selection of a correct response. Analysis to this level of detail was not carried out on the data from the present experiment.

It was suggested earlier that the reduction in the proportion of errors in SAI represented the subject's ability to learn to ignore the effects of motion with practice. It is further suggested here that anticipation plays a role in this learning process. As a sequence of stimuli is presented, the subject learns that there is a limited set of visual-motion combinations presented to him (i.e., he learns something about the composition of the stimulus events, including the probability that a particular stimulus combination may occur). Rather than ignore motion in SAI, for example, he learns that a stick deflection in the direction of the platform motion will result in a correct response. Beneficial anticipation allows the subject to select from the possible stimulus alternatives and then prepare himself for control stick deflections in the opposite direction (but the same axis) from the one expected to reduce conflict. As indicated previously, this process was more difficult in DAI because the visual-motion combinations were twice those in SAI. Finally, it is proposed that anticipation may serve to account for the effects discussed next.

Amendment Time

When a control movement is executed in the wrong direction, the subject must initiate a correction. The time interval between the onset of an error response and the onset of the correction is referred to as amendment time. Gibbs (1965) found that with practice his subjects were able to reduce amendment time on errors from .24 to

.11 sec. He claimed that the latter figure was much too short for visual feedback to occur. Gibbs inferred that kinesthetic feedback from the incorrect movement facilitated the subject and allowed him to make a very rapid correction. An investigation reported by Keele and Posner (1968) would tend to support this notion. They found that it takes 190-260 msec to process visual feedback.

In an experiment similar to that of Gibbs', Angel and Higgins (1969) found also that subjects are able to arrest a movement in less than the estimated time needed for visual feedback. That kinesthetic feedback accounts for the rapid amendment time, however, is subject to question. Chernikoff and Taylor (1952) reported kinesthetic reaction time to be 118.9 msec and concluded that this time period was much too long to permit continuous voluntary movements through feedback. In a more recent experiment, Higgins and Angel (1970) measured kinesthetic reaction time and amendment time to errors in a task similar to the one used by Gibbs. They found that kinesthetic reaction time ranged 108-169 msec, but amendment time ranged 83-122 msec. Finally, Angel, Garland, and Fischler (1971) conducted a study to make certain that visual feedback did not play a role. Using a tracking task, they hid the response marker from view until it was more than half way to the target position. It was found that errors were corrected while the marker was still out of view!

If neither visual nor kinesthetic sensory feedback plays a role, how then are errors detected? Adams' (1968) closed-loop theory states "that the consequences of a response with sufficient habit strength to

occur are fed back and compared with a reference which is the desired value for the system. Any difference between a reference and its response feedback is error, and detection of error results in a response sequence that can lead to error nulling" (p. 493). This theory, however, assumes that "proprioceptive stimuli can guide well-learned responses because current proprioceptive stimuli from our movements are compared against their reference levels from past learning and are recognized as correct" (p. 499). Adams (1961) suggested that under certain conditions, such as tracking, the restraints of an elementary efferent-afferent loop can be sidestepped. Guidance is then received from learned internal sources. In citing other investigators Adams concluded that learning to anticipate sequences may be characteristics of tracking tasks and result in shortened reaction time values.

Keele (1968) offered an alternative interpretation. He suggested "that at the appearance of a signal, a motor command is issued to move in the most probable direction. As the signal is further processed, the correct direction is determined and compared with the just issued command, and if there is a discrepancy, a motor command to reverse direction is issued" (p. 395). He claimed that motor programs (i.e., motor commands) can be structured before a movement takes place and that the movement itself is carried out uninfluenced by peripheral feedback (i.e., an open-loop control). Thus, the feedback involved in a correction of a response is of central origin. This concept serves to understand the process involved in a series of predictable movements. Angel and his colleagues offered a similar suggestion; the subject is

able to monitor his own behavior internally with some reference value. Responses are then arrested prematurely before information is fed back from the periphery.

As noted in the Results, amendment times in the present experiment were comparable to those reported by the investigators cited above. Pilots tended to have shorter amendment times than navigators and inexperienced subjects. The average time for each of these groups in Session 4 was .06, .12, and .11 sec., respectively, in SAI. Previous experience with tracking tasks may account for the differences between pilots and non-pilots. It may also account for the significant reduction of amendment time with practice among pilots. Nevertheless, all subjects reduced time to levels below those that are claimed to be needed to process visual and kinesthetic feedback. Obviously, information from both senses was available, but it contained no information as to the correctness of the response (as would be claimed by some of the previously cited investigators). Yet, as indicated several times, the corrective responses were almost always in the appropriate direction and axis. It could be argued that motion in SAI provided cues and allowed the processing of proprioceptive feedback (perhaps vestibular) to occur before the processing of visual feedback began. Possible evidence was cited earlier to the effect that an operator may receive information from proprioceptive senses in advance of those received through visual ones (Matheny, et al., 1963). The present experiment provided further support to this possibility. To determine whether motion had an effect on amendment time, it was decided to compute these

measures from data obtained in the last session of the experimental condition where motion cues were absent (VO) and where the visual-motion relationships were compatible (SAC). Amendment time ranged .10-.18 sec. on both VO and SAC. Thus, it is concluded that motion cues were not responsible for these short amendment times.

If motion cues are not involved in the subject's ability to recognize his own mistakes so rapidly, by what means is error detection mediated? Higgins and Angel (1970) suggested that the subject is able to monitor his own motor commands with some reference value and arrests the response prematurely when there is a discrepancy, before information is fed back from the senses. It is proposed here that anticipatory behavior is heavily involved in error detection, but that the responses are <u>not</u> arrested prematurely (although they may be premature for feedback to occur). To maintain smooth control, it is possible that the subject need not depend on feedback at all.

The following conceptual model is offered for consideration: The subject begins processing information prior to the onset of the stimulus and has a rough expectation that the chosen response has some probability of being in error. The subject terminates the process early and in his haste to respond makes an error. At this point he has stimulus information still available, but awaits for confirmation that the original decision was in fact erroneous. To maintain smooth tracking performance, the subject decreases the rate of control stick deflection and terminates the movement when the original expectation of an error is confirmed. The correction of the error then proceeds and the response is influenced by the same variables as an originally correct one.

Evidence for the above comes from two sources. First it is assumed that a correct response is initiated when the processing of the stimulus is complete. This processing takes time and results in longer RT, but faster MR. If processing is incomplete as in the case of errors, then additional time is needed. Moreover, if RT to a correct response is representative of the minimal time needed to process stimulus information, then the point where correction time is computed must represent the time needed to complete the processing of the visual information available to the subject when he has made an error. Confirmation of this possibility was obtained when RTs on correct responses were compared to correct RTs to reversal errors. The difference failed to reach significance, although there was a very slight tendency for correction RTs to be shorter than those of the originally correct responses. In addition, RTs on reversal errors did not increase with practice (to provide time needed for continued information processing). In fact the RTs remained relatively homogeneous throughout (Gottsdanker, 1956, also found that RTs to errors are stable regardless of practice), but there was an observable decrease in correction RTs. This finding suggests that once a decision is made, the response proceeds without modification until processing of the stimulus information is complete and the original expectation of an error is confirmed. With practice the subjects learns to process the information at a higher rate (or learns the probabilities of the stimulus events) and is able to maintain smoother performance.

The above discussion implies that a subject compensates for short RTs associated with errors by decreasing the rate of movement. A

decrease in MR would provide the subject with the additional time needed to complete the processing of stimulus information and allow him to halt the movement sooner, but not prematurely. The latter is not without support from other sources. Beare and Kahn (1967), for example, found that tracking error decreases as the average rate of stick movement decreases. Accordingly, the second evidence for the proposed conceptual model comes from an analysis of MRs on reversal errors.

Welford (1968) noted that the execution of movements is in many ways distinct from decisions to initiate them. Attempts to find a correlation between RT and the speed of a movement have been reported by several investigators. Clark and Glines (1962), Henry (1961), and Smith (1965) found little or no correlations and concluded that the speed of a movement cannot be predicted from knowledge of reaction time. Most of these studies were conducted with large muscle groups or even with whole body movements and the distances were usually very long.

When the RTs on correct responses and reversal errors were correlated with MRs on these responses in the present experiment, it was found that there was a definite positive relationship, $r = .57$; $\underline{t}$ (141) = 8.22, $\underline{p} < .01$. It was concluded that the short RTs, characteristic of errors, are associated with slow MRs and that the longer RTs on correct responses are followed with faster MRs. This finding provides some confirmation to the notion that the subject compensates for the shortness of his error RT by decreasing the rate of his control movement. A slower movement need not be committed to run its full course; rather, it can be modified and terminated when the subject has completed the necessary information processing functions.

To summarize the foregoing analysis, it appears that anticipatory behavior has a bearing on the short amendment time reported by several investigators and also found in the present experiment. The subject has some expectation of making an error and responds rapidly before the necessary processing of the stimulus information is complete. He then slows his movement in order to continue processing and sampling the stimulus information. A corrective response, having the same or similar characteristics of an originally correct one, is then executed. It is further claimed that this process can occur without recourse to sensory information fed back from the subject's control actions. The information provided by the stimulus is processed, not the error added by the erroneous maneuver.

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Appendix A

PRELIMINARY INVESTIGATION

The purpose of this preliminary investigation was to assess the suitability of the experimental configuration, including the equipment, tasks, procedures, and performance measures for the issues being explored. Accordingly, it was of interest to ascertain whether the overall methodology employed would result in trends in the predicted direction. To avoid duplication in the discussion of this investigation, it will be assumed that the reader has reviewed the Experimental Procedure.

Method

Apparatus

The visual system, motion system, operator station, experimenter station, and computer system interfaces were those described in the Experimental Procedure. Prior to the initiation of the preliminary investigation, considerable effort was devoted to the selection and implementation of appropriate hardware/software for the experiment. Several subjects (pilots and non-pilots) participated in pre-preliminary tests to determine: (1) ideal locations for targets on the terrain model; (2) appropriate visual and motion displacement

rates; (3) ideal control stick sensitivity; and (4) the best methods for data acquisition and extraction.

Training and Experimental Tasks

Both the training and experimental tasks were identical to those described in the Experimental Procedure.

Experimental Conditions

Four of the five conditions described in the Experimental Procedure were employed. These were: visual only (VO); motion only (MO); single axis incompatible (SAI); and single axis compatible (SAC).

Subjects

Twelve male volunteers, all uniformed members of the United States Air Force, served as subjects. These subjects were assigned to one of three experience groups consisting of four pilots, four navigators, and four non-rated (inexperienced) officers. Each subject was administered a questionnaire (see Appendices B, C. and D) in order to obtain relevant background information. The results are summarized below:

Pilots. The average age of the pilots was 36.3 and ranged from 29 to 46 years. All possessed at least four years of higher education (mean, 5.5 years and a range of 4 to 8 years). The mean number of flying hours was 1,337 with a range of 700 to 3,890. The mean number of years of flying experience was 9.8. All pilots were right handed and none reported a susceptibility to motion sickness.

Navigators. The average age of navigators was 41.5 and ranged from 37 to 46 years. All possessed at least five years of higher

education (mean, 5.9 years and a range of 5 to 6 years). The number of flying hours was 4,070 of navigational experience with a range of 3,350 to 5,100). The mean number of years of experience was 16.1. Three of the four navigators reported that they had some informal pilot experience, but in all cases this had occurred at least 7 years prior to the experiment. One navigator was left handed and none reported a susceptibility to motion sickness.

Non-rated. The average age of the non-rated subjects was 30.3, with a range of 25 to 36 years. All possessed at least six years of higher education (mean, 6.1 and a range of 6 to 6.5 years). None reported having previous formal or informal piloting experience. All of these subjects were right handed and none reported a susceptibility to motion sickness.

Design

One subject from each of the experience groups was assigned randomly to one of the four conditions. The design was identical to that reported in the Experimental Procedure, except that data were acquired over three experimental sessions, rather than four. Thus the total number of trials was 120, instead of 160, on each subject. A summary of the total number of trials and responses in the preliminary investigation is provided in Table 28.

Procedures

The procedures were identical to those reported in the Experimental Procedure.

TABLE 28

Summary of Total Number of Trials and Responses in the Preliminary Investigation

Visual stimulus

Conditions	Ss	Pitch: Correct responses	Pitch: Reversal errors	Pitch: Axis errors	Pitch: Cross cpld	Roll: Correct responses	Roll: Reversal errors	Roll: Axis errors	Roll: Cross cpld	Total resp.	Data loss	Total Trials
VO	Pilot	35	4	5	1	48	2	5	2	102	18	120
	Navig.	48	5	3	1	47	6	5	1	116	4	120
	N-R	46	5	1	0	53	0	5	2	112	8	120
SAI	Pilot	29	20	4	1	23	19	12	0	108	12	120
	Navig.	25	14	1	0	31	7	6	1	85	15	100[a]
	N-R	31	14	1	0	25	17	6	0	94	4	100[a]
SAC	Pilot	50	5	5	0	50	2	7	0	119	1	120
	Navig.	48	1	2	1	52	0	4	0	108	12	120
	N-R	41	4	7	0	36	9	12	0'	109	11	120

Motion stimulus

Conditions	Ss	Pitch: "Consistent"	Pitch: "Inconsistent"	Roll: "Consistent"	Roll: "Inconsistent"	Total resp.	Data loss	Total Trials
MO	Pilot	2	0	4	0	6	2	120
	Navig.	8	6	8	6	28	6	120
	N-R	6	3	6	8	23	11	120

[a]Equipment problems prevented the presentation of two blocks of trials.

Performance Measures

Data acquisition. Data acquisition was identical to that reported in the Experimental Procedure.

Tolerance limits on control stick activity. As explained in the Experimental Procedure, data obtained for this preliminary investigation were used to obtain the tolerance limit values to be employed as decision criteria for presenting subjects with trial stimuli, as well as to identify the temporal location in the tracking records in which the subject responded to a stimulus. Obviously, tolerance limits were not available prior to the preliminary investigation. Thus, it was particularly important to insure that trial stimuli be presented to the subjects under the most stable conditions and when stick activity was minimal, if not at zero precent.

Computed performance measures. The computed measures of performance were restricted to (1) response time (RT) on correct responses, reversal errors, and axis errors; (2) movement rates (MR) for correct responses, reversal errors, and axis errors; and (3) the proportion of errors. The methods of computation were identical to those presented in the Experimental Procedure.

Results

The data obtained from the preliminary investigation were reduced to means and proportions, but were not submitted to statistical analyses. The results are presented as observable trends in the data only.

RT and MR in VO, SAI, and SAC

Correct responses. The mean RTs to correct responses are summarized in Table 29. There was a tendency for VO to result in longer RTs than SAI and SAC (.72, .66, .64 sec., respectively). These differences, however, were more clearly evident in the roll axis (.80, .71, and .67 sec.) than pitch (.64, .59, and .60 sec.). The pilots tended to respond with shorter RTs than navigators and non-rated subjects, but the mean differences were extremely small (.66, .68, and .68 sec., respectively). The pilot in the SAC condition, however, was slower in responding than the non-pilots (this may have been due to the rather infrequent flying experience reported by this subject).

TABLE 29

Mean Response Times (in sec.) to Correct Responses and to Reversal and Axis Errors in VO, SAI, and SAC

		Pitch			Roll		
Conditions	Subjects	Correct responses	Reversal errors	Axis errors	Correct responses	Reversal errors	Axis errors
VO	Pilot	.63	.20	.43	.78	.33	.69
	Navig.	.60	.57	.42	.82	.40	.46
	Non-rated	.69	.48	.20	.81	--	.33
SAI	Pilot	.51	.41	.36	.64	.40	.42
	Navig.	.66	.60	.30	.75	.63	.53
	Non-rated	.61	.50	.20	.75	.56	.45
SAC	Pilot	.66	.48	.32	.72	.35	.47
	Navig.	.53	.30	.30	.63	--	.36
	Non-rated	.62	.46	.43	.67	.56	.46

The mean MRs on correct responses are presented in Table 30. There was a strong tendency for MRs to be slower in SAC than VO and SAI (1.5, 2.1, 4.1°/.05 sec., respectively). MRs in SAI were faster than in VO and SAC on both axes. There was no appreciable difference in MR between pilots, navigators, and non-rated subjects (2.6, 2.6, and 2.5°/.05 sec.). Mean MR to pitch was somewhat slower than to roll, but the difference was very small (2.3 vs. 2.8°/.05 sec.). Differences, however, were more clearly evident in SAI (3.7 vs. 5.1°/.05 sec.) than VO (2.2 vs. 2.1°/.05 sec.) and SAC (1.2 vs. 1.7°/.05 sec.).

TABLE 30

Mean Movement Rates (in °/.05 sec.) to Correct Responses and to Reversal and Axis Errors in VO, SAI, and SAC

		Pitch			Roll		
Conditions	Subjects	Correct responses	Reversal errors	Axis errors	Correct responses	Reversal errors	Axis errors
VO	Pilots	2.8	.2	.8	2.2	.3	.6
	Navig.	2.5	1.7	1.7	2.0	.9	.4
	Non-rated	1.2	.6	.3	2.0	—	.3
SAI	Pilots	3.6	1.3	1.7	4.7	2.3	.8
	Navig.	3.6	1.6	1.3	4.1	3.1	.7
	Non-rated	3.9	2.7	1.8	4.5	1.6	.9
SAC	Pilots	1.0	.9	1.2	1.1	.3	.3
	Navig.	1.2	.2	.6	1.9	—	.4
	Non-rated	1.3	.4	1.8	2.1	1.3	.4

Reversal errors. Mean RTs are presented in Table 29. In contrast to correct responses, mean RTs on reversal errors appeared to be about the same on all conditions, except that SAI resulted in slightly longer RT (.52 sec.) than VO (.41 sec.) and SAC (.41 sec.). As with correct

responses, pilot RT was shorter (.37 sec.) than navigators' and non-rated subjects (.47 and .51 sec.). Mean RT on the pitch axis was slightly shorter than roll, but the difference was very small (.44 vs. .46 sec.). Mean reversal error RTs were consistently shorter than correct responses on both axes (.44 vs. .61 sec. on pitch and .46 vs. .72 sec. on roll).

Mean MRs on reversal errors are summarized in Table 30. MRs in SAI tended to be faster than VO and SAC (2.1, .7, and .6°/.05 sec., respectively). There was little observable difference between pilots, navigators, and non-rated subjects (.9, 1.3, and 1.2°/.05 sec., respectively). Mean MR on the pitch axis tended to be slower than roll, but the difference was very small (1.1 vs. 1.4°/.05 sec., respectively). Mean MRs to reversals were slower than to correct responses on both axes (1.1 vs. 2.3°/.05 sec. on pitch and 1.4 vs. 2.8°/.05 sec. on roll).

Axis errors. Mean RTs to axis errors are summarized in Table 29. RTs tended to be longer in VO than SAI and SAC, but the difference was small (.42, .38, and .35 sec., respectively). Non-pilot RTs tended to be shorter than pilot RT, but the difference was small (.45, .40, .35 sec., respectively). Pitch RT was shorter than roll (.33 vs. .46 sec.). As with reversals, axis error RTs were consistently shorter than correct responses on both axes (.33 vs. .61 sec. on pitch and .46 vs. .72 sec. on roll).

Mean MRs associated with axis errors are shown in Table 30. MRs in SAI tended to be faster than VO and SAC (1.2, 17, and .8°/.05 sec., respectively). There was no difference in MRs between pilots, navigators and non-rated officers (.9, .9, and .9°/.05 sec., respectively).

Unlike correct responses and reversal errors, MRs associated with axis errors were slower on roll than pitch (.5 vs. 1.2°/.05 sec.). It must be noted, however, that an axis error on pitch was due to a lateral stick deflection. MRs were typically faster on lateral than longitudinal stick. As with reversals, MRs associated with axis errors were slower than correct responses on both axes (1.2 vs. 2.3°/.05 sec. on pitch and .5 vs. 2.8°/.05 sec. on roll).

RT and MR in MO

A response in this condition was considered an error. Two types of errors were possible: "consistent" and "inconsistent." A "consistent" response was one in which axis and directionality of stick deflection was commensurate with the expected response to motion. An "inconsistent" response was one in which stick deflection was either on the wrong axis and/or direction with respect to motion. As noted from the data presented in Table 28, there were very few responses made to this condition. Table 31 shows the mean RTs and MRs on "consistent" responses only. Pilots tended to have shorter RTs than navigators and non-rated subjects (.45, .65, and .61 sec., respectively). There was no appreciable difference in mean MRs between pilots, navigators, and non-rated (.4, 1.1, and .6°/.05 sec.). Unlike other responses to the other conditions, pitch RTs were longer than roll (.65 vs. .48 sec.) and there was practically no difference in MRs (.6 vs. .7°/.05 sec.).

In summary, the results obtained in the MO condition were somewhat inconclusive, except that pilot RTs tended to be shorter than those of non-pilots.

TABLE 31

Mean Response Times (in sec.) and Movement Rates (in °/.05 sec.) in Condition MO ("Consistent" Only)

	Pitch		Roll	
Subjects	RT	MR	RT	MR
Pilot	.60	.3	.30	.4
Navigator	.80	1.4	.50	.7
Non-rated	.56	.2	.65	.9

Error Rates in VO, SAI, and SAC

Reversal errors. The proportions of reversal errors are summarized in Table 32. All subjects made a greater proportion of reversal errors in SAI than VO and SAC (.32, .07, and .06). The effect of practice, as measured by the proportion of reversal errors over the three sessions, was evidenced in SAI (.49, .27, and .22) by all subjects (pilots: .59, .30, and .22; navigators: .28, .17, and .24; non-rated: .59, .33, and .20). No such effect was found in VO (.05, .09, and .08) and only slightly in SAC (.11, .03, and .05). The reduction in errors in SAC between the first and second session was due to the non-rated subject. Finally, practice tended to have its effect primarily in the first session.

In general, there was no substantial difference in the proportion of errors by pilots, navigators, and non-rated subjects (.16, .11, and .18), although the navigator tended to make less errors in SAI (.23) than the pilot (.37) and the non-rated subject (.37). There was a tendency for pitch stimuli to result in a greater proportion of reversal errors than roll, but the difference was small (.17 vs. .13).

TABLE 32

Proportion of Reversal and Axis Errors

Conditions	Subjects	Pitch Reversal errors	Pitch Axis errors	Roll Reversal errors	Roll Axis errors
	Pilot	.10	.11	.02	.09
VO	Navigator	.10	.05	.10	.08
	Non-rated	.10	.02	.00	.08
	Pilot	.36	.07	.37	.22
SAI	Navigator	.33	.03	.12	.13
	Non-rated	.35	.02	.38	.13
	Pilot	.08	.08	.04	.12
SAC	Navigator	.02	.04	.00	.07
	Non-rated	.08	.14	.15	.21

Axis errors. The proportions of axis errors are presented in Table 32. All experimental conditions resulted in about the same proportion of axis errors (.07, .10, and .11 on VO, SAI, and SAC, respectively). Practice did not have an effect on the proportion of errors made as evidenced by their rather random distribution over sessions. There was no substantial difference between pilots, navigators, and non-rated subjects (.12, .07, and .10). Finally, there was a consistent tendency among all subjects to make a greater proportion of axis errors on roll than pitch (.12 vs. .06).

Proportion of Responses in the MO Condition

The proportion of responses to MO are presented in Table 33. As will be recalled, these errors were classified into "consistent" and "inconsistent" responses, depending on whether they were commensurate

TABLE 33

Proportion of "Consistent" and "Inconsistent" Responses in MO

	Pitch		Roll	
Subjects	"Consistent"	"Inconsistent"	"Consistent"	"Inconsistent"
Pilot	.03	.00	.07	.00
Navigator	.14	.11	.14	.11
Non-rated	.11	.05	.11	.14

with the motion function. It will be noted from the data in Table 33 that the pilot made no "inconsistent" responses, whereas non-pilot (i.e., navigator and non-rated) errors were almost equally divided between "consistent" and "inconsistent" on both pitch (.13 vs. .08) and roll (.13 vs. .13). The results suggest that the responses made by non-pilots were random, but that motion served as a cue to the pilot, even in the absence of the expected visual cues.

Summary

Effects of Visual-Proprioceptive

Visual-proprioceptive conflict, as represented by the SAI condition, tended to result in longer RTs on correct responses, with this effect being particularly evident on the roll axis. The absence of motion cues (VO), also tended to retard RT on roll, but the effect was not as strong. While correct responses resulted in longer RTs under conditions of conflict, the MRs were faster on both axes. Also, the absence of motion cues tended to increase MRs.

Reversal error RTs were slightly longer in the conflict condition and this was coupled with faster MRs. There was only a small difference in RTs associated with axis errors between conditions, although the conflict condition tended to result in shorter RTs and faster MRs. Finally, a consistent finding was that reversal and axis errors had shorter RTs than correct responses and the MRs were always slower.

The most compelling evidence for conflict was the larger proportion of reversal errors in SAI as compared to VO and SAC. In addition, the effects of practice were mainly in the conflict condition, where most of the learning was expected to occur. In contrast to reversals, the proportion of axis errors was low in all conditions and there was no effect that could be attributed to practice.

Effects of Prior Experience

There was some tendency for pilots to respond with shorter RTs than non-pilots. This finding was particularly evident on correct responses and axis errors in the conflict condition. Movement rates did not show an effect due to practice.

All subjects made more reversals in SAI than in the other conditions, but the differences between experience groups over all of the conditions were very small. The navigator made a smaller proportion of reversal errors in SAI than did the pilot and the non-rated subject, and most of the learning occurred with the latter two. To some extent, the large proportion of reversal errors made by the non-rated subject in SAI can be attributed to his inexperience in performing tracking tasks. Evidence for this conclusion can be found in the compatible condition

(SAC) in which the non-rated subject made more reversal errors than the pilot and the navigator. Finally, and as anticipated, there was no difference in the proportion of axis errors between experience groups.

Evidence for the effect of motion cues on performance of pilots can be found in the MO condition. The pilot RTs in this condition were shorter than those of non-pilots and all of his responses were "consistent" relative to motion. Since non-pilot responses were randomly distributed between "consistent" and "inconsistent" responses, it cannot be ascertained whether these subjects actually responded to the motion stimuli.

Effect of Axis

Response times to correct responses were consistently slower on roll than pitch and the MRs were generally faster, although the latter was more clearly evident in the conflict condition. Neither reversal nor axis error RTs and MRs showed strong effects due to axis. Finally, it had been anticipated that roll stimuli would result in a greater proportion of reversal errors than pitch, but no such evidence was found in the data (the results were somewhat mixed, with some subjects making more errors on roll than pitch and others making more errors on pitch).

Conclusions

In general, the results of this preliminary investigation were encouraging. Some of the data, however, did not reveal the strong effects that had been anticipated (e.g., the effect of axis on errors), but much of the variability in the data could easily be attributed to factors associated with the selection of subjects. Upon completion of this investigation, it was concluded that (1) the experimental procedures were satisfactory; (2) the methods for computing performance measures also were satisfactory; but (3) greater care needed to be taken in selecting subjects for the experiment.

Appendix B

QUESTIONNAIRE FOR PILOTS

PILOTS

NAME ______________________ Telephone extension __________ Symbol ______
Last First MI

(1) Rank ______ (2) Date of birth __________ (3) Years of higher education _____

(4) Degree(s) ______ (5) Field of study ________________

(6) Duty AFSC ______ (7) Title ______________ (8) Job Title ______________

(9) Organization ____________________

(10) Flying status: (a) Code _______ (b) Date _______

(11) Most recent aircraft piloted: (a) Type of aircraft _______ (b) Date ________

(12) Types of military aircraft in which you were checked out:

(a) Type of aircraft	(b) Duty AFSC	(c) Crew positions	(d) Flying hours	(e) Number of years	(f) Instructor (Yes/No)

(13) Duty aircraft in order of proficiency (high to low):

(a) Type of aircraft	(b) Crew positions	(c) Last year flown

(14) Have you ever had civilian pilot training/experience? (a) Yes ______ (b) No ______

(15) If Item 14 is Yes, please answer the following:

Date completed pilot training (a) Pre-solo _______ (b) Solo _______
Do you, or have you ever held a civilian pilot's license? (c) Yes ____ (d) No____
Type(s) of civilian pilot's license held: (e) ____________________
Total hours logged in civilian aircraft: (f) ____________________
Approximate date of most recent piloting of civilian aircraft: (g) __________
Type(s) of civilian aircraft piloted (h) ____________________

(16) Have you ever participated as a subject in an experiment in which you were asked to track a target or maintain a heading using visual and/or motion cues?
(a) Yes _______ (b) No _______ (c) Approximate date _______
(year)

If answer is Yes, please describe the task performed in the experiment: __________

____

____

(17) Have you ever had operational and/or informal experience with remotely pilot vehicles? (a) Yes _______ (b) No _______

If answer is Yes, please describe the task:

____

____

(18) Do you have operational experience piloting: (a) gliders? _______ (b) Boats? ___

(19) In the past year, what percentage of your flying time was spent in actual weather conditions? (a) approximate percentage? _______ (b) Aircraft? _______________

(20) Have you ever experienced temporary confusions in interpreting aircraft attitude indicators? (a) Yes _______ (b) No _______

If answer is Yes, please describe experience: _______________________________

____

(21) Do you tend to get: (a) carsick? _______ (b) airsick? _______ (c) seasick? ___

(22) Are you: (a) left handed? _______ (b) right handed? _______ (c) ambidextrous? ___

Appendix C

QUESTIONNAIRE FOR NAVIGATORS

NAVIGATORS

NAME ______________________________ TELEPHONE EXT __________ SYMBOL __________
Last First MI

(1) Rank ________ (2) Date of birth __________ (3) Years of higher education ___

(4) Degree(s) ____________ (5) Field of Study ______________

(6) Duty AFSC ____________ (7) Title ____________ (8) Job Title ____________

(9) Organization ______________________________

(10) Flying status: (a) Code _________ (b) Date _________

(11) Most recent aircraft navigated: (a) Type of aircraft _________ (b) Date ______

(12) Types of military aircraft in which you were checked out:

(a) Type of Aircraft	(b) Duty AFSC	(c) Crew position(s)	(d) Flying Hours	(e) No of Years	(f) Instructor (Yes/No)

(13) Duty aircraft in order of proficiency (high to low):

(a) Type of Aircraft	(b) Crew Positions	(c) Last Year Flown

(14) Have you ever had formal pilot training/experience? (a) Yes ____ (b) No _____

(15) If Item 14 is Yes, please answer the following:

Date military pilot training terminated (a) Presolo _________ (b) Solo ______

Date civilian pilot training terminated (c) Presolo _________ (d) Solo ______

Hours logged during all training (e) Presolo ________ (f) Solo ___________

NAVIGATORS (Continued)

(16) Have you ever had informal pilot experience (e.g., observation, "back seat," ground simulator)? (a) Yes ______ (b) No ______

If answer is Yes, please describe the experience: ______________________

____

____

(17) Have you ever participated as a subject in an experiment in which you were asked to track a target or maintain a heading using visual and/or motion cues? (a) Yes ______ (b) No ______ (c) Approximate date ______
Year

(18) Have you ever had operational and/or informal experience with remotely piloted vehicles? (a) Yes ______ (b) No ______

If answer is Yes, please describe the task:

____

____

(19) Do you have operational experience piloting: (a) gliders?______ (b) boats?______

(20) Do you tend to get:: (a) carsick?______ (b) airsick?______ (c) seasick?______

(21) Are you: (a) left handed?______ (b) right handed?______ (c) ambidextrous?______

Appendix D

QUESTIONNAIRE FOR NON-RATED OFFICERS

NON-RATED OFFICERS

NAME ______________________ Telephone extension ______ Symbol ______
Last First MI

(1) Rank _____ (2) Date of bitth ________ (3) Years of higher education ________

(4) Degree(s) ________ (5) Field of Study ________________

(6) Duty AFSC ______ (7) Title __________ (8) Job Title ____________

(9) Organization ______________________

(10) Have you ever had pilot training/experience? (a) Yes ____ (b) No ________

(11) If Item 10 is Yes, please answer the following:

Date military pilot training terminated (a) Pre-solo ______ (b) Solo ______
Date civilian pilot training terminated (c) Pre-solo ______ (d) Solo ______
Hours logged during all training (e) Pre-solo ______ (f) Solo ______

(12) Have you ever had informal pilot experience (e.g., observation, "back seat", ground simulator)? (a) Yes ______ (b) No ______

If answer is Yes, please describe the experience: ______________

____

____

(13) Have you ever participated as a subject in an experiment in which you were asked to track a target or maintain a heading using visual and/or motion cues? (a) Yes ______ (b) No ______ (c) Approximate date ________
(year)

If answer is Yes, please describe the task you performed in the experiment:

____

____

(14) Have you ever had operational and/or informal experience with remotely piloted vehicles? (a) Yes ______ (b) No ______

If answer is Yes, please describe the task:

____

____

(15) Do you have operational experience piloting: (a) gliders? ______ (b) boats? ___

(16) Do you tend to get: (a) carsick? ____ (b) airsick? ____ (c) seasick? ___

(17) Are you: (a) left handed? ____ (b) right handed? ____ (c) ambidextrous? ____

Appendix E

SUMMARY OF RESPONSES TO QUESTIONNAIRE

TABLE 34

Summary of Responses to Questionnaire

Data category	Pilots	Navigators	Non-rated
<u>Age</u>			
Mean	34.5	33.3	31.2
Median	34.5	33.5	30.5
Range	26-45	25-44	23-44
<u>Higher Education</u>			
Mean (years)	5.3	5.4	5.8
Range	4-7	4-8	4-8
<u>Degrees</u>			
Bachelor	9	8	4
Masters	11	7	11
Ph.D.	0	1	1
<u>Most Recent Flying Experience</u>			
Mean (months)	5.97	8.97	Not applicable
Median	3	6	Not applicable
<u>Types of Aircraft Flown</u> (*n* = Ss reporting)			
Trainers	20	8	Not applicable
High performance	11	2	Not applicable
Multi-engine	8	21	Not applicable
Helicopters	1	0	Not applicable
Miscellaneous	3	0	Not applicable
<u>Highest Proficiency</u> (*n* = Ss reporting)			
Trainers	8	1	Not applicable
High performance	6	1	Not applicable
Multi-engine	5	14	Not applicable
Helicopters	0	0	Not applicable
Miscellaneous	1	0	Not applicable

TABLE 34 (cont'd)

Data category	Pilots	Navigators	Non-rated
Most Recent Experience (n = Ss Reporting)			
Trainers	8	4	Not applicable
High performance	5	1	Not applicable
Multi-engine	6	11	Not applicable
Helicopters	0	0	Not applicable
Miscellaneous	1	0	Not applicable
Total Flying Hours			
Mean	2953	2531	Not applicable
Median	2924	2499	Not applicable
Range	350-5100	620-5700	Not applicable
Mean Flying Hours/ Aircraft			
Trainers	1467	344	Not applicable
High performance	1200	776	Not applicable
Multi-engine	1198	1735	Not applicable
Helicopters	1350	0	Not applicable
Miscellaneous	350	0	Not applicable
Years of Flying Experience			
Mean	9.85	8.1	Not applicable
Median	10.25	7.25	Not applicable
Range	3-32	2.5-10	Not applicable
Civilian Pilot Experience			
Yes	13	Not applicable	Not applicable
No	7	Not applicable	Not applicable
Mean (hours)	160	Not applicable	Not applicable
Range (hours)	15-400	Not applicable	Not applicable

TABLE 34 (cont'd)

Data category	Pilots	Navigators	Non-rated
<u>Civilian Pilot Training by Non-pilots Only</u> (presolo only)			
Yes	Not applicable	4	2
No	Not applicable	12	14
Mean years since training	Not applicable	9	7
<u>Informal Pilot Experience</u> (i.e.g, observation)			
Yes	Not applicable	9	5
No	Not applicable	7	10
<u>Experience in Other Experiments</u>			
Yes	2	1	2
No	18	15	14
<u>Experience with Remotely Piloted Vehicles</u>			
Yes	2	0	2
No	18	16	14
<u>Experience with Gliders and/or Boats</u>			
Gliders	3	0	0
Boats	3	5	3
Neither	15	11	13
<u>Motion Sickness</u> (n = Ss reporting)			
Carsick	1	0	0
Airsick	0	2	2
Seasick	1	1	1

TABLE 34 (cont'd)

Data category	Pilots	Navigators	Non-rated
Handedness			
Right handed	19	15	15
Left handed	1	1	0
Ambidextrous	0	0	1
Flying Time in Weather in Last Year			
Yes	15	Not applicable	Not applicable
Mean percent time	24	Not applicable	Not applicable
Confusions with Indicators			
Yes	12	Not applicable	Not applicable
No	8	Not applicable	Not applicable

Appendix F

SUMMARY OF TOTAL NUMBER OF TRIALS AND RESPONSES

TABLE 35

Summary of Total Number of Trials and Responses

		Visual stimulus										
		Pitch				Roll						
Conditions	Groups	Correct responses	Reversal errors	Axis errors	Cross cpld	Correct responses	Reversal errors	Axis errors	Cross cpld	Total resp	Data loss	Total trials
VO	Pilots	253	22	16	6	230	36	20	21	604	36	640
	Navig.	228	24	28	4	210	34	29	21	578	62	640
	N-R	243	24	20	5	192	46	20	37	587	43	630[a]
SAI	Pilots	220	61	16	2	142	120	26	16	603	37	640
	Navig.	213	56	18	1	194	68	25	19	594	46	640
	N-R	206	66	23	1	184	78	41	6	605	36	640
SAC	Pilots	250	14	14	8	250	10	12	22	580	60	640
	Navig.	210	21	18	6	221	22	26	21	545	95[b]	640
	N-R	240	32	9	8	217	18	39	24	587	53	640
DAI	Pilots	170	25	71	0	126	10	147	10	559	81[c]	640
		Motion stimulus										
		Pitch				Roll						
		"Consistent"[d]		"Inconsistent"[e]		"Consistent"		"Inconsistent"				
MO	Pilots	37		3		45		5		90	40[f]	640
	Navig.	28		21		26		16		91	62	640
	N-R	35		14		28		9		76	50	640

[a]Equipment problems prevented the presentation of a block of trials to one subject.

[b]Twenty trials were not recorded due to equipment problems.

[c]Of this total number, 17 trials resulted in axis errors in the wrong direction with respect to motion.

[d]The number of responses in the correct axis with respect to motion.

[e]The number of responses in the incorrect direction, but correct axis, with respect to motion.

[f]Ten trials were not recorded due to equipment problems.

Appendix G

INSTRUCTIONS FOR SESSION 1

We appreciate your acceptance and willingness to participate as a subject in this experiment. As was explained to you earlier, each subject in this experiment is asked to be present for five sessions on five consecutive days for approximately a half hour each day. Since several subjects will participate, it is important that you arrive on time for each session so that other subjects need not wait for long periods. It is recognized that unpredictable circumstances may prevent you from reaching the Laboratory on time or may require that you miss a session. If either of these situations arise, please call this Laboratory with anticipation so that your session may be rescheduled. Upon completion of the fifth session you will be given a briefing on the purposes of this experiment. Please do not discuss this research with other personnel until it has been completed, as they may be participants at a later date. It is anticipated that this research will be completed by June.

In this experiment you will be asked to conduct control activities to maneuver a remotely piloted vehicle (or RPV) through a specified course. The equipment used in this experiment simulates an airborne control station containing the equipment necessary to operate an RPV.

Included in this flight control station is a television monitor, side arm control stick, and other equipment necessary to maneuver the RPV. The television picture you will see simulates the scene as viewed by a television camera mounted in the nose of the RPV. The RPV, and accordingly the television image, will respond to the commands of the control stick. When the stick is moved to the right or left, the RPV will bank to the right or left and produce a right or left turn. When the stick is pulled back, the RPV will climb and you will notice that the horizon on the TV screen will move down. Finally, when the stick is pushed forward, the RPV will dive and you will notice a corresponding upward movement of the horizon on the TV screen. Rate of change in the attitude of the RPV depends on the proportion of control stick displacement.

In this experiment your task will be to fly the RPV through a specified course. You will observe a series of sequential targets on the TV screen as you follow the course and your task will be to maintain each target in your field of view. In addition, you are to maintain the horizon as level as possible in the center of the TV screen. As you have the RPV approach and fly over one of these targets you will note the next target close to the horizon. Maneuver the RPV so that this new target is close to the center of the TV screen and then level the horizon so that it is also in the center of the screen. Once you have flown the RPV over the first five targets, you will encounter a series of target-like signs with arrows. These arrows indicate that you must continuously bank the RPV to the left until you reach the next series of targets.

Fly the RPV over these next five targets as you did the first five. Once the RPV has reached the final target you will be given a rest before repeating the series.

The RPV will be flown at approximately 150 knots and at an altitude not to exceed 1000 feet or less than 180 feet. If the RPV reaches an altitude of less than 180 feet, a flashing light above the altitude indicator will give you a warning and you must pitch the RPV up until the light is off. If 1000 feet is exceeded the warning light will remain on and you must pitch down until the light is off. You will probably find it most comfortable to fly the RPV between 250 and 500 feet.

The floor switch allows you to communicate with personnel at the experimenter control station. If you wish to communicate with the experimenter, or respond to his instructions, press the switch and proceed with the communication while it is pressed. Release the switch as soon as you have finished since return communications cannot be accomplished while it is pressed.

The course you will fly will be demonstrated by an experimenter in order to better acquaint you with the experiment and required task. Feel free to ask questions regarding the task you will be performing. After the demonstration has been completed, you will fly the RPV in the presence of an experimenter. Again, feel free to ask any questions you wish.

Appendix H

PROCEDURES FOR COMPUTING TOLERANCE LIMITS

This appendix describes the procedures used for determining the tolerance limits. Obviously, it was necessary to select tolerance limit values prior to actual experimentation. These values would then be used as decision criteria on all experimental blocks and on computer routines to extract data stored on magnetic tape. This need was satisfied with data collected in the preliminary investigation (see Appendix A).

Briefly, the method for obtaining tolerance limits was simply to conduct a frequency count of control stick activity at various levels of deflection. The data were obtained from both the lateral and longitudinal deflections, which as indicated earlier, had been recorded every .05 sec. Thus, it was possible to compute the percent of time that the subject maintained his stick at or within preselected levels of deflection.

The procedures for obtaining tolerance limits required that certain data be excluded and that various levels of deflection be identified for the frequency count. Excluded was all tracking data between targets 5 and 6. Also excluded was the activity resulting from responses to experimental trials. Except for the VO condition, data

representing five seconds of tracking after the onset of a trial (i.e., one second represented the visual stimulus duration, one second represented the return of motion to the level position, plus an additional three seconds) were disregarded. The five second period was an approximation of the average time required for subjects to null the effects of a trial stimulus. Since the VO condition did not include motion, the time period excluded from the analysis was limited to four seconds.

The percent of time that the subject maintained the control stick at or within each level of deflection was computed independently for lateral and longitudinal stick, with direction pooled, in accordance with the following equation:

$$\text{Percent time} = \frac{\text{Number of samples at or below level X}}{\text{Total number of samples}} \times 100$$

The levels selected for this procedure were: 15, 20, 25, 30, 40, 50, 60, 70, 80, 90 percent deflection on lateral stick and 4, 6, 8, 10, 12, 14, 16, 20, 40, 60, 80 on longitudinal stick. (The difference in levels between lateral and longitudinal stick was due to the amount of activity found in each. Since the least amount was found on the latter, it was necessary to select a greater number of values at the lower end.) The next step was to select a standard value in the time continuum that would be representative of most stick activity, but still allow small deflections. This value was set arbitrarily at 75 percent. Computation of the frequencies on the preliminary investigation showed that the

average lateral stick activity was at or below ±20 percent deflection 75 percent of the time. Similarly, longitudinal stick activity was at or below ±7 percent 75 percent of the time.[4] The difference between these two is understandable since most of the tracking corrections required lateral stick deflections. These two values were used as decision criteria for presenting the subject with trials in the experiment.

The above procedure was repeated on data collected in the experiment. The results, presented in Figure 22, show that the tolerance limits were identical to those found in the preliminary investigation. Thus, these two values (±20 percent for lateral and ±7 percent for longitudinal stick deflections) were used for computing the performance measures.

It could be argued that this method of obtaining computed measures of performance would result in a certain amount of non-task related variability. This variability would be said to occur in cases where the onset of a response actually began prior to the point where stick deflection crossed the tolerance limit (e.g., 4 percent lateral stick deflection) in contrast to responses that began precisely at, or slightly above the tolerance limit (e.g., 21 percent lateral stick deflection).

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[4]It must be pointed out that the 75 percent value was not selected on the basis of an arbitrary decision alone. A count of subject responses obtained from the stored data was made at values above and below 75 percent (i.e., above and below ±20 percent lateral and ± 7 percent longitudinal stick). By setting the standard value too high (e.g., 85 percent) some legitimate responses were not retrieved because the maximum stick deflections on those responses were relatively low. On the other hand, by setting the standard value too low (e.g., 65 percent), some small stick deflections occurring prior to the actual responses were retrieved as responses. The standard 75 percent represented the value for which the least amount of data was lost and the most efficient in identifying and retrieving legitimate responses.

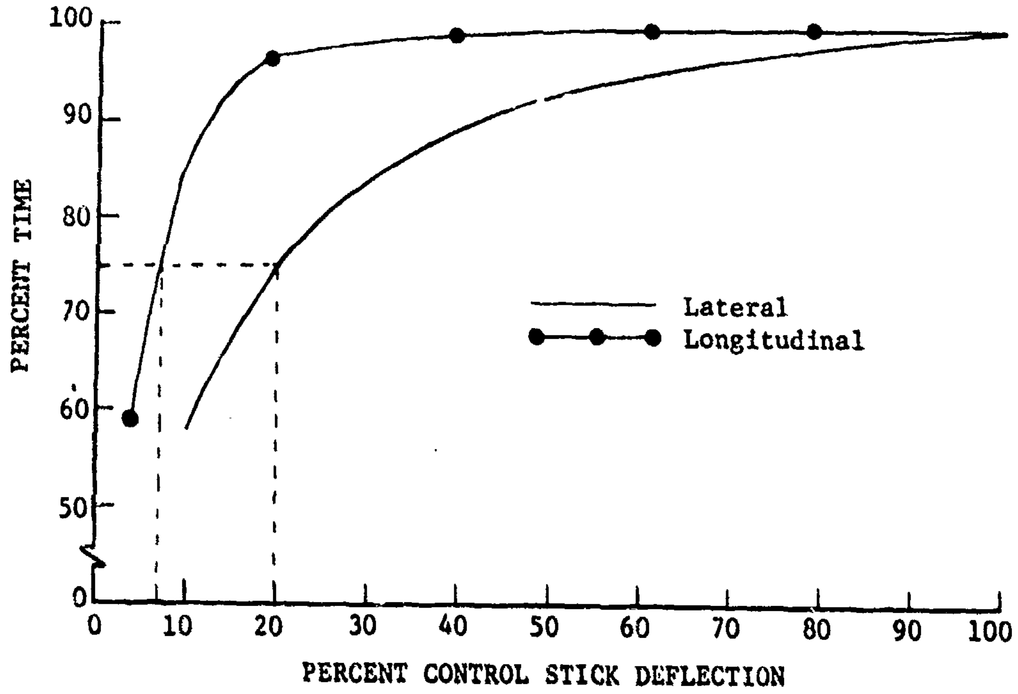

Figure 22. Percent time spent at or within various levels of control stick deflection. 75 percent represented the standard used to select tolerance limits for lateral and longitudinal stick. Thus (see dashed lines), the average lateral control stick activity was at or below 20 percent deflection 75 percent of the time. Similarly, the average longitudinal control stick activity was at or below 7 percent deflection 75 percent of the time.

This argument was refuted on the basis of two related factors. First, an effort was made by the experimenter to insure that all trials be presented to the subjects in accordance with the decision criteria discussed in the Procedures. This meant that the control stick activity be well within the tolerance limits, if not at zero percent. Data resulting from the few occasions in which a trial was inadvertently presented when the subject's stick was above the tolerance limit, were

regarded as experimenter error and were not included in the analysis (see <u>Computed Performance Measures</u>). Secondly, the differences that could produce variability (e.g., in response times) due to this method of data extraction were negligible and rarely exceeded .05 sec. (i.e., the equivalent of one sample).

Another method of determining the onset of a response would be to measure the point of initial control stick acceleration. While this method could result in greater precision in determining response time than the one used in this experiment, a requirement for bands of allowable tolerance (i.e., noise) would still be needed; otherwise, accelerations associated with small, but non-task related, stick deflections would be identified as legitimate responses.

Appendix I

F RATIOS FROM THE ANALYSES OF VARIANCE ON

PROPORTIONS OF REVERSAL ERRORS

TABLE 36

F Ratios from the Analyses of Variance on Proportions of Reversal Errors

Conditions	Experience groups	Sessions (df = 3, 9)	Axis (df = 1, 3)	Sessions × Axis (df = 3, 9)
VO	Pilots	.93	4.41	1.00
	Navigators	4.12[a]	20.76[a]	2.25
	Non-rated	1.02	5.42	.69
SAI	Pilots	6.58[a]	6.28	1.40
	Navigators	12.84[b]	1.04	2.65
	Non-rated	6.64[a]	.61	.56
SAC	Pilots	.44	.67	.17
	Navigators	3.76	.03	.27
	Non-rated	.64	.70	.13

[a] $p < .05$

[b] $p < .01$

Appendix J

F RATIOS FROM THE ANALYSES OF VARIANCE ON PROPORTIONS OF AXIS ERRORS

TABLE 37

F Ratios from the Analyses of Variance on Proportions of Axis Errors

Conditions	Experience groups	Sessions (df = 3, 9)	Axis (df = 1, 3)	Sessions × Axis (df = 3, 9)
VO	Pilots	1.22	.33	1.77
	Navigators	1.82	.20	1.30
	Non-rated	.25	.01	.14
SAI	Pilots	1.04	1.80	2.00
	Navigators	2.12	.60	1.33
	Non-rated	2.61	2.00	2.69
SAC	Pilots	2.35	.50	.50
	Navigators	3.56	.15	.25
	Non-rated	.40	3.68	.20

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